

Tone–Vowel Interaction in Mandarin: Effects of Prominence and Vowel Height

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Lexical tones in Mandarin function as phonological distinctions, but their realization extends beyond F0 modulation. Prior work shows that supralaryngeal adjustments—often described as a “tongue-pulling effect”—systematically contribute to tonal differentiation, revealing a structured tone–segment relationship, particularly in the lowering of vowel gestures under low tones due to their mechanical linkage [1, 2, 3]. This pattern aligns with the view that tones participate in syllable-level gestural organization [4, 5], where their coordination with vowels creates conditions for tone–vowel interaction. Articulatory studies further substantiate this claim: tones modulate vowel articulation in systematic ways [6]. For example, /a/ produced with a low tone (T3) shows a lower and backer tongue position than with a high tone (T1), whereas comparable effects are not observed for /i/. This asymmetry likely reflects differences in constriction degree and sonority: the highly constricted, low-sonority /i/ requires greater articulatory precision and thus shows stronger resistance to coarticulation than the more open /a/ [7, 8]. These resistance-based differences become especially evident in prosodically prominent contexts. Building on this observation, the present study examines tone–segment interaction in greater detail, asking whether focus-induced prominence—known to trigger localized hyperarticulation and enhance phonological contrasts [9, 10]—modulates tonal influence on vowel articulation not only for /a/ but also for the more coarticulatorily resistant /i/, and how intrinsic differences between high and low vowels further shape this modulation.

Focus types were manipulated to include *tonal contrast* with segments held constant (Table 1a), *segmental (onset) contrast* with tones held constant (Table 1b), *broad focus* without either contrast (Table 1c), and an *unfocused* condition (Table 1d). Articulatory data from eight native Mandarin speakers (4F) were collected using EMA. For each vowel (/i/, /a/), four minimal pairs contrasting either in tone or onset were used (e.g., tonal: *ma1–ma3*, *pa1–pa3*; segmental: *pa1–ma1*, *pa3–ma3*). Vertical tongue-body movement trajectories were extracted using MView, over a window spanning 50ms before vowel onset to 50ms after vowel offset: high–low movement patterns for /a/ and low–high movement patterns for /i/. To characterize dynamic tonal effects over time, we fit generalized additive mixed models (GAMMs) to the trajectories and visualized smooths and difference curves to identify statistically meaningful intervals of divergence.

As summarized in Fig. 1, tonal effects on the vertical tongue movement are evident under both tonal and segmental contrast: vowels carrying a low tone (T3) are produced with lower tongue positions than those carrying a high tone (T1) over significant portions of the vocalic trajectory (Fig. 1a–b, a'–b'). Under broad focus, however, this effect is attenuated—present only for /a/ (Fig. 1c) and absent for /i/ (Fig. 1c'). In the unfocused condition, tonal effects are absent for both vowels. Visual inspection further reveals vowel-specific patterns: For /a/, tonal influence appears gradient—strongest under tonal contrast, somewhat reduced under segmental contrast, further diminished under broad focus, and absent when unfocused (Fig. 1a–d). For /i/, a comparable downward trend is observable, but the gradation is less consistent, showing a clearer split between the contrastive-focus conditions and the other two (Fig. 1a'–d').

The findings demonstrate that tone–segment interaction in Mandarin is jointly shaped by prominence and vowel-specific coarticulatory resistance. Under contrastive focus, low tones (T3) exert a strong “tongue-pulling” effect on /a/. This effect weakens under broad focus and disappears when unfocused, indicating that tonal articulation is not obligatory but enhanced when information-structural demands heighten phonological contrast. A comparable effect is also present for the more coarticulatorily resistant /i/, although much attenuated. In other words, the same mechanical linkage operates on /i/, but the markedly weaker and less differentiated tonal patterns align with a resistance-based account: the greater constriction and stability of high vowels limit the articulatory expression of tone. Thus, the results indicate that tone-induced articulatory adjustments arise from an interaction between tone–tongue mechanics and vowel-specific constraints, which is itself conditioned by prominence. This, in turn, suggests that multiple articulatory subsystems can be recruited collectively to reinforce tonal contrasts, but only when communicative demands for enhanced contrast are sufficiently high.

Table 1. Example mini-dialogues illustrating each Focus Type for the target word /ma3/. Each version of Sentence A provides a question designed to elicit one of the focus conditions (a)-(d), with the contrast-triggering words underlined. Each version of Sentence B provides an answer to A, with the target word underlined and the focused words in bold.

Focus type		Example sentences	
(a)	Tonal	A: [<u>ma</u> 1 tɿ0 pai2 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2 ma0 ?]	B: [pu4, ma1 ma0] # [<u>ma</u> 3 tɿ0 pai2 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2.]
	contrast	Did the white chess of Ma1 defeat the king ?	No, mom. The white chess of Ma3 defeated the king.
(b)	Segmental	A: [<u>pa</u> 3 tɿ0 pai2 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2 ma0 ?]	B: [pu4, ma1 ma0] # [<u>ma</u> 3 tɿ0 pai2 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2.]
	contrast	Did the white chess of Ba3 defeat the king ?	No, mom. The white chess of Ma3 defeated the king.
(c)	Broad	A: [pa03 peɪ4, ni3 ʃuo1 ʃən2 mɿ0 ?]	B: [uo3 ʃuo1 ma1 ma0] # [ma3 tɿ0 pai2 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2.]
	focus	Baby, what did you say?	I said “mom, the white chess of Ma3 defeated the king.”
(d)	Unfocused	A: [ma3 tɿ0 <u>mi</u> 3 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2 ma0 ?]	B: [pu4, ma1 ma0] # [<u>ma</u> 3 tɿ0 pai2 tɛ ^h i2 ta3 pai4 lɿ0 waŋ2.]
		Did the beige chess of Ma1 defeat the king ?	No, mom. The white chess of Ma3 defeated the king.

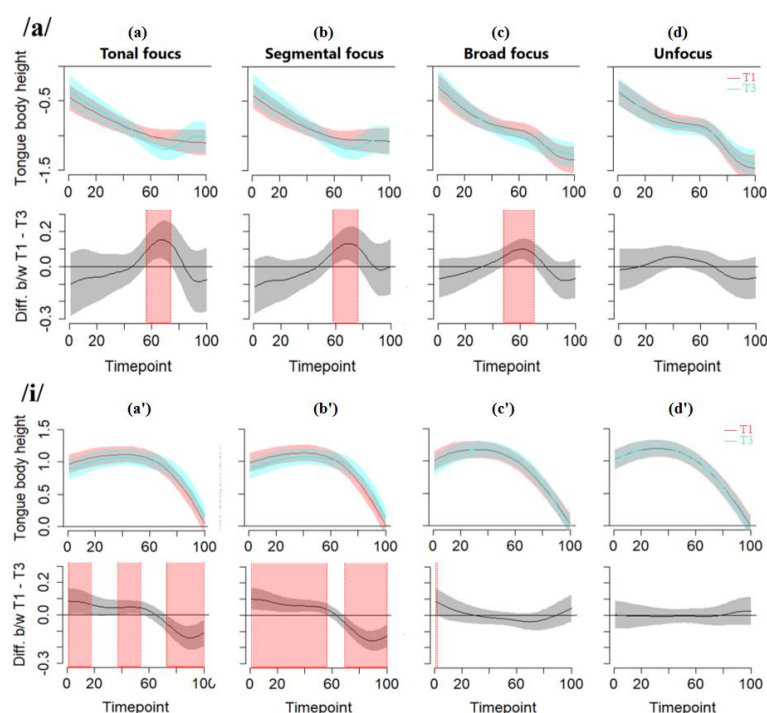


Figure 1. GAMM smooths of tongue-body vertical movement trajectories by tone (T1 vs. T3), with corresponding difference plots for /a/ (top two panels) and /i/ (bottom two panels). Columns (a)-(d) show the planned focus conditions for /a/, and columns (a')-(d') those for /i/. In the smooth plots, T1 is shown in pink and T3 in light blue; in the difference plots, red shading marks the temporal interval where the two tones differ.

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