Vowel coarticulation with alveopalatal sibilants in Mandarin

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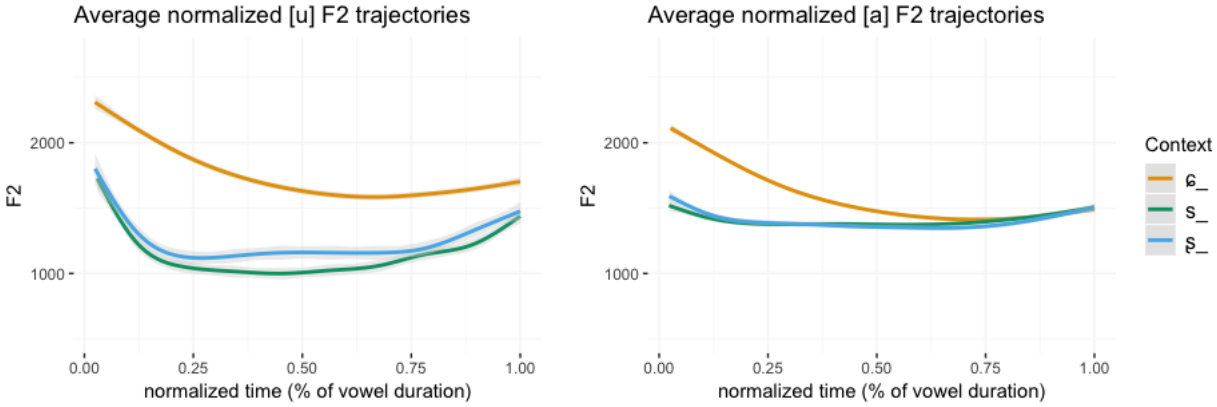
Introduction: Previous work has shown that transitions to vowels following alveopalatal sibilants in Mandarin typically exhibit raised second formant (F2) values (e.g. Stevens et al., 2004). Perceptual studies have also shown F2 onset/transitions to be a primary cue distinguishing the alveopalatal sibilant from the other sibilants (Li, 2008). This paper re-examines the acoustic effects of palatalizing coarticulation in Mandarin. While previous studies have focused on differences in F2 transitions or values at vowel onset, we find that the raised F2 values following alveopalatal sibilants persist through the entire duration of the vowel, regardless of vowel length. We discuss potential articulatory influences as well as implications for perception and phonological analyses of Mandarin.

The vowel inventory of Mandarin is frequently assumed to be /i y u ə a/ (e.g. Duanmu, 2000, 2007). The three sibilants /s ʂ ɕ/ can all occur before [a] and [u]/[əu], but neutralize to [ɕ] before [i] (Duanmu, 2007; Li, 2008). Vowels [a] and [u]/[əu] following [ɕ] have sometimes been described as diphthongs [ia] and [iu] respectively. Ladefoged and Maddieson (1996) claim there is simply a normal transition with no independent evidence for a diphthong analysis. We therefore adpot monophthong transcriptions in this paper (following e.g. Lee-Kim, 2014).

Methods: Data was obtained from 11 native Mandarin speakers during a laboratory speech production task. Speakers were international students at a US university, with most originally from the Beijing area. The stimuli were mono- and bisyllabic words with word-initial [s ʂ ɕ] followed by vowels [a u] placed in the carrier phrase "wǒ bǎ X dú yī biàn" ('I read X once').

Results: Average normalized F2 trajectories for vowels [u] and [a] are shown in Figure 1. As expected, we found consistent differences in onset F2 following the alveopalatal [ɕ] relative to the other sibilant contexts. We also found that these differences consistently persisted throughout the entire duration of the vowel for [u] and consistently persisted through at least 50%-75% of the vowel duration for [a]. The speakers showed variation in mean F2 values and amount of within-category variance, but these general patterns of F2 raising were consistent across all speakers.

Figure 1: Averaged normalized [u a] F2 trajectories



We performed a mixed-effects linear regression predicting F2 at vowel *offset* (as we are interested in whether the fronting effect persists through the entire vowel). The results showed that F2 values of [u] at vowel offset are significantly raised when following [ɕ]. We included vowel duration as a predictor to ensure that these findings could not be attributed to vowel length (e.g. overall shorter [u] vowels). If the coarticulatory F2 raising does not extend

through the entire vowel, but instead has a fixed temporal extension, we expect to see F2 offset decrease with vowel duration. We actually observed that F2 offset significantly *increases* with vowel duration for both vowels following [ɕ]–longer vowels have relatively higher F2 offset. Therefore, it is not the case that the prolonged extent the F2 raising is simply an artifact of shorter vowels.

Discussion: These results show that the influence of the alveopalatal sibilant on the following vowel is not merely in the transition to the vowel; vowels following [ɕ] have a higher F2 for most of the vowel duration (if not the entire vowel). Although previous work has focused on vowel onset or transition, our results are not entirely unexpected given previous work on alveopalatal articulation. Substantial coarticulatory fronting in vowels following alveopalatals has been documented in several languages (see e.g. Recasens, 1999, for discussion). Recasens also suggests that tongue fronting may additionally facilitate lip rounding, which could potentially explain the acoustic differences we observe between rounded [u] and unrounded [a].

Our results raise several questions about the phonological representations of the segments and the nature of coarticulatory fronting in Mandarin. Solé (2007) proposes that phonetic or "mechanical" effects should have temporal extensions which are independent of speech rate. Therefore, if raised F2 were a purely mechanical effect, we would see raised F2 for a fixed period of time. In our results, duration of raised F2 is not fixed; [u] F2 is raised throughout the entire vowel regardless of vowel duration, and [a] F2 is raised through at least 50% of the vowel regardless of vowel duration. This suggests that vowel fronting may be phonological rather than "mechanical". The near categorical nature of [u] F2 raising also provides empirical support for using the front rounded vowel in phonological surface representations: [ɕy] instead of [ɕu]/[ɕəu].

Previous work on perception has found that Mandarin speakers use F2 at vowel *onset* as a primary cue for distinguishing [ɕ] from [s ʂ] (Li, 2008). Our results suggest the potential for a stronger perceptual effect—Mandarin speakers may be able to identify the preceding fricative from only hearing the following vowel, or even only the offset of the following vowel. Further perception work will need to be done to determine exactly how listeners use the entirety of vocalic information for sibilant identification.

Conclusion: We have presented data from Mandarin where vowels following alveopalatal sibilants exhibit prolonged effects of coarticulatory vowel fronting with raised F2. This differs from previously described alveopalatal coarticulation as only affecting vowel onset or transition. We demonstrate that coarticulatory vowel fronting affects the whole segment for /u/ and at least 50% of the segment for /a/, regardless of vowel duration. These effects are consistent across tokens and speakers. Further work will need to be done to clarify potential articulatory sources of the vowel-specific effects on /a/ and /u/ and determine how Mandarin listeners might use this vocalic information in perception.

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