Early production of boundary tones in Mandarin declaratives: Contour clustering of monolingual and bilingual child speech

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Introduction. In Mandarin, pitch conveys both lexical and intonational information, creating conflicts at utterance-final positions. To mitigate potential tonal crowding, intonational tones can be successively appended over a lengthened syllable, or simultaneously added to a lexical tone and leading to its undershooting (rescaling or truncation) [1-2]. While prior experimental work has shown that Mandarin-speaking children can produce successive addition boundary tones (SuABT) by around age two [3], little is known about the variability of early intonational productions during tone language acquisition, nor about the developmental trajectory of boundary tone realisation in naturalistic speech.

This study investigated how Mandarin-speaking children acquire boundary tones during the second year of life, drawing on naturalistic speech data from CHCC [4] and Tong corpus [5] (see Table 1) and employing a contour-clustering approach. Specifically, the study examined (i) whether and how children at three developmental time points (2;01, 2;06, and 2;11) produce boundary tones, (ii) how production patterns change over time, and (iii) whether lexical tone category or bilingualism influences boundary-tone realisation.

Methods. Declarative utterances ending with full lexical tones were extracted, with each utterance-final syllable coded for lexical tone category (T1, T2, T3, or T4). Using the Contour Clustering GUI [6], time-series f0 (20 measurement points per syllable) and duration measures were cleaned by removing missing values or extreme rates of change. F0 was converted to semitones, and its velocity was calculated. All measures were speaker-standardised.

Hierarchical agglomerative clustering (complete linkage) was then performed separately for the four lexical tones, using dynamic time warping with f0 velocity and duration as predictors. For each tone category, the data were initially partitioned into eight clusters in order to exclude singular outliers and clearly mispronounced tokens, resulting in a total of 300 T1 syllables, 209 T2 syllables, 247 T3 syllables, and 292 T4 syllables. The optimal number of clusters was subsequently determined by evaluating within- and between-cluster variance.

After inspection of the time-series f0, velocity, and duration, the clusters were reclassified into three contour categories: canonical, undershot, and SuABT. As illustrated in Fig.1, canonical T2 (cluster 2 & 4) exhibited a full rising contour; undershot T2 (cluster 1) was scaled lower than the canonical cluster; SuABT (cluster 3 & 5) were realised as a late decline following the lexical rise. Notably, undershot T3 (cluster 2 & 3) showed a half T3 sandhi pattern, viz. the canonical dipping contour was truncated into a low fall. Percentages of SuABT, canonical, and undershot contours were calculated per Speaker × Age × Tone (Fig.2), and were analysed using Dirichlet Regression [7] with speaker, age, and tone as predictors.

Results and Discussion. The results revealed a strong effect of age on contour categories. At 02;11, the proportion of SuABT contours decreased significantly (cf. 02;01, $\beta = -2.12$, $p < .001$), accompanied by a reduction in canonical contours (cf. 02;01, $\beta = -1.97$, $p < .001$). Meanwhile, SuABT was significantly less frequent in T2 and T3 than in T1 (T2: $\beta = -1.20$, $p = .015$; T3: $\beta = -1.34$, $p = .013$); canonical contours showed the same pattern (T2: $\beta = -1.91$, $p < .001$; T3: $\beta = -2.10$, $p < .001$). Regarding speaker effects, relative to the monolingual child (Tong), Luna showed a significantly higher proportion of SuABT ($\beta = 1.29$, $p = .017$), whereas Avia exhibited a significantly lower proportion of undershot contours ($\beta = -0.99$, $p = .047$). This study provides the first corpus-based evidence that Mandarin-speaking children, both monolingual and bilingual, acquire boundary tones early in development. Future work should explore the role of utterance length and sentence-final particle in boundary tone acquisition, and how these factors might further differentiate bilingual from monolingual trajectories.

Table 1. Background of subjects and data from CHCC and the Tong corpus (MLU = mean length of utterance).

Child	Data	MLU	Child	Data	MLU	Child	Data	MLU
Tong (Mandarin monolingual)	2;01.17	2.82	Avia (Mandarin-English bilingual)	2;01.11	3.20	Luna (Mandarin-English bilingual)	2;01.03	1.56
	2;06.13	3.52		2;01.18	2.97		2;01.24	1.22
	2;11.08	3.53		2;01.29	2.75		2;06.01	3.16
				2;06.09	3.75		2;06.11	2.86
				2;06.26	2.62		2;06.29	1.92
				2;11.12	3.92		2;11.04	2.08
							2;11.13	2.98

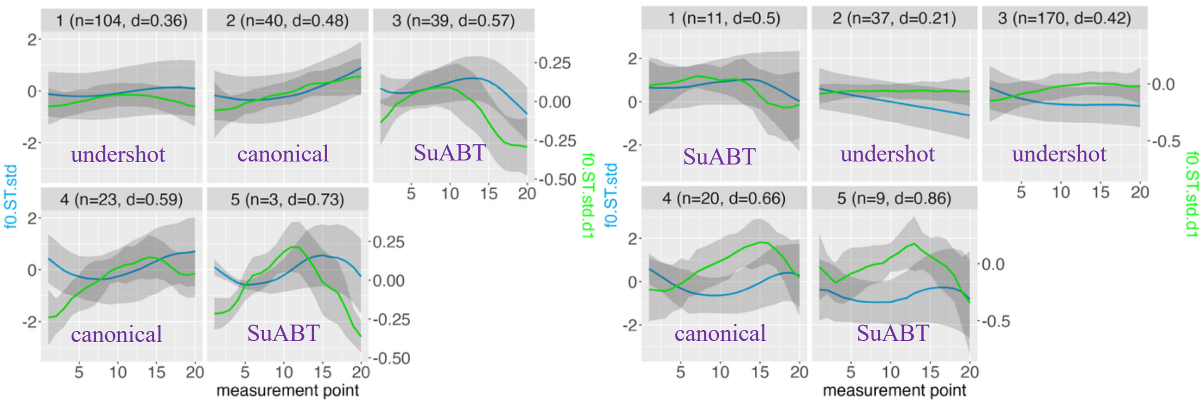

Fig. 1. Clustering results of T2 (left) & T3 (right);
f0 contour in blue, f0 velocity in green, d = mean duration, grey band = standard deviation.

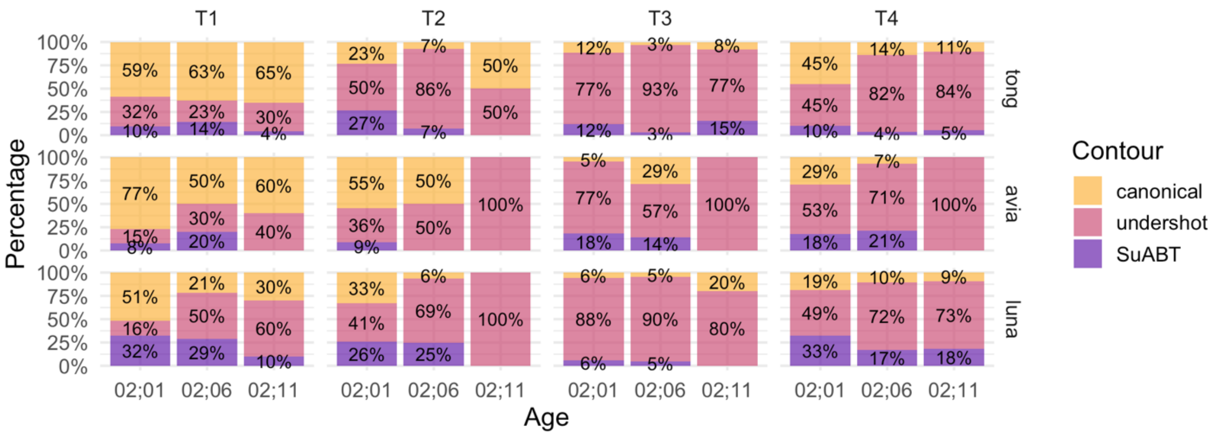

Fig. 2. Proportion of contour categories (Speaker × Age × Tone) for different declarative-final lexical tones produced by the three children.

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