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Onset-tone interaction in Mundabli

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Abstract. This paper presents an acoustic study of Mundabli tones from original fieldwork data, specifically focusing on interactions of onset consonant type (voiceless obstruents, voiced obstruents, and sonorants) and (f_0) level and trajectory of tones. Our results reveal that voiceless obstruents condition an abrupt rise in f_0 at vowel onset, while voiced obstruents and sonorants maintain similar, relatively steady f_0 levels, providing evidence for an account of onset-f_0 interaction in which only voiceless consonants condition f_0 raising. In addition, we note that Mundabli's dense tonal inventory does not appear to constrain these interactions, as might be expected under accounts of speech production that relate within-category variation to the density of contrast in an inventory.

Keywords. tone acoustics; onset-tone interaction; Mundabli; Lower Fungom language

1. Introduction.

1.1. ONSET-f_0 EFFECTS. The fundamental frequency (f_0) of vowels is often influenced by the characteristics of the consonants that precede them (Lehiste & Peterson 1961; Chen 2011; Kirby & Ladd 2016; Xu & Xu 2021; Gao & Kirby 2024). We henceforth refer to this collection of phenomena as onset-f_0 effects. This phenomenon is widely regarded as central to tonogenesis, with phonologization of onset-f_0 effects a crucial step in most models of the development of contrastive tones (Haudricourt 1954; Thurgood 2002; Michaud & Sands 2020).

The most commonly observed pattern of onset-f_0 effects is a raising of f_0 after voiceless obstruents compared to voiced obstruents. One commonly advanced account of onset-f_0 effects, such as that advanced in Gao & Kirby (2024), holds that there are two distinct effects: the raising of f_0 following voiceless obstruents and the lowering of f_0 during and/or following voiced obstruents. Both effects have distinct, clear physiological mechanisms which are thought to lead to uncontrolled, automatic interaction of consonants and the f_0 trajectories of tones. The raised f_0 associated with voiceless obstruents can be attributed to physiological gestures aimed at suppressing vocal-fold vibration during oral occlusion (Hanson 2009; Kirby & Ladd 2016), and the lowered f_0 associated with voiced obstruents has been linked to larynx lowering, which facilitates vocal-fold vibration during oral occlusion (Hoole & Honda 2011; Solé 2018).

However, onset-f_0 effects are variable cross-linguistically. Some variability can be expected at a baseline due to interactions with local and global prosody (Xu & Xu 2003). The lowering effect thought to be associated with voiced obstruents ranges from the local perturbations discussed above, to temporally more extensive effects often referred to as tone depression (Rose 2002; Chen & Downing 2011; Lotven & Berkson 2019), to the development of register systems with maximally extensive f_0 effects and additional formant and/or voice quality differences (Jiang & Kuang 2016; Gehrmann 2022; Rose & Yang 2022; Brunelle et al. 2022). These language-specific

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implementation differences suggest that at least some onset-f_0 effects are controllable and possibly learned, as research on a limited set of the world's languages has suggested (see, for instance, Kingston & Diehl 1994).

1.2. INTERACTIONS WITH TONE AND DENSITY OF TONE CONTRAST. In tonal languages, another possible mediating effect on onset-f_0 effects can be found: the presence of contrastive tone and the associated pressure to maintain contrast could reasonably lead speakers to reduce the size of onset-f_0 effects, if tonal contrast is at risk and if onset-f_0 effects are at any level under speaker control. A specific claim that onset-f_0 effects are smaller in tonal languages is advanced in Hombert (1978), but where tonal languages have been researched, an onset-f_0 effect can generally be found which is not obviously reduced in magnitude compared to those of non-tonal languages (Hombert 1977; Jessen & Roux 2002; Chen 2011). Given the limited research in this area, it is likely that this question has yet to be settled.

It stands to reason that languages with a particularly large number of tones are more likely to show constrained onset-f_0 effects, if such constraints can be found. Dispersion Theory (DT) holds that linguistic systems are organized to maximize, or at least create sufficient, acoustic distinctions to support the maintenance of perceptual distinctions (Liljencrants & Lindblom 1972; Lindblom 1986). According to the framework advanced in Lindblom (1986) in particular, languages with larger phonological inventories are expected to exhibit tighter clustering within individual categories, with the more precise production ensuring less overlap in the limited possibility space of speech production. However, more recent work on contrast implementation in phonemic inventories of varying sizes does not suggest that the number of categories is straightforwardly relevant; rather, the language-specific weighting of particular dimensions of contrast determines which aspects of production are actually constrained (Hauser 2021, 2022). It is in the context of these debates–over onset-f_0 effects specifically and constraints on variation related to contrast implementation generally–that we attempt to investigate onset-f_0 effects in a language with a particularly large number of tones.

1.3. BACKGROUND: MUNDABLI. Mundabli (ISO 639-3: boe; Glottocode: mund1328) is a Yemne-Kimbi or Western Beboid language spoken by about 800 speakers (Good et al. 2011) in northwestern Cameroon. Mundabli is one of the languages of Lower Fungom, a micro-region at the north edge of the Cameroon Grassfields (Figure 1) noted for its intense multilingualism and convergence of languages around a similar typological profile (Good et al. 2011; Di Carlo et al. 2020). Mundabli is morphologically isolating, and its lexemes are mostly monosyllabic, having lost much of the overt affixal material that characterizes other Lower Fungom languages, particularly noun class agreement markers.

Despite other aspects of Mundabli's phonetics and phonology being studied in recent years (Voll 2009; Faytak et al. 2023, 2024), the phonetic details of the language's tonal system remain under-explored. Its tone system is complex by global standards, though it is not especially complex among languages of the Grassfields or Lower Fungom. Voll (2017) analyzes the language with four level tones and four contour tones, all of which occur on monosyllabic words as shown in Table 1. Tone has a high functional load in Mundabli, with numerous minimal pairs depending on tone contrast. Tone also heavily features in non-concatenative morphology as described in Voll (2017), including the marking of noun purality and the tense and aspect of verbs. The high-low falling (HL) contour occurs primarily in loanwords and is by far the least frequently occurring tone in Voll's materials; this led her to speculate that this tone may not be distinguished from

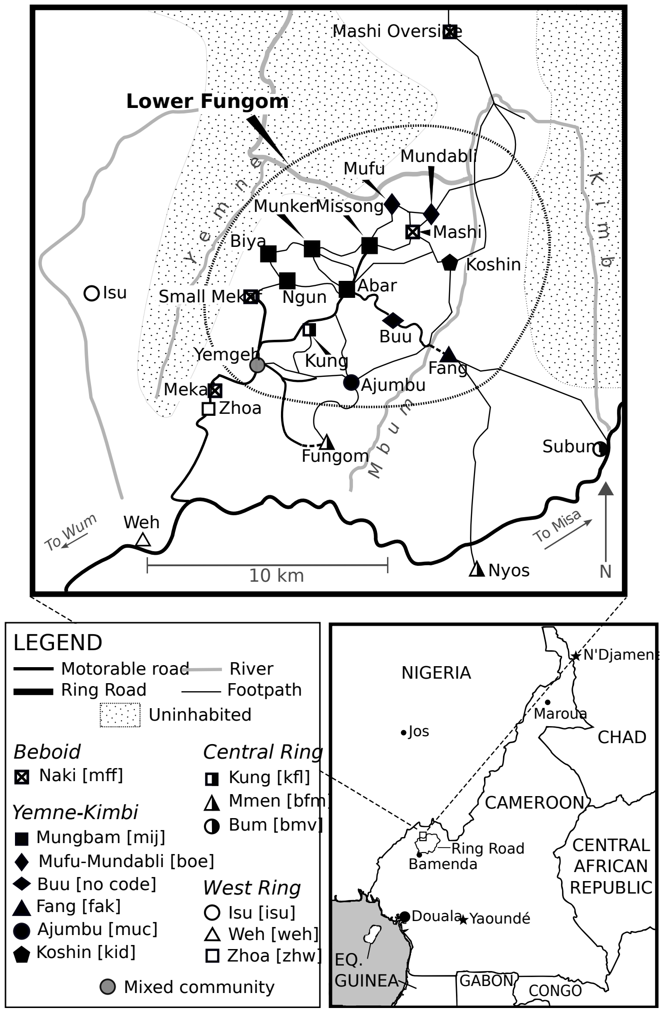

Figure 1. Map of Lower Fungom, with the village of Mundabli at upper right; figure from Di Carlo et al. (2020).

the ML tone by some speakers (Voll 2017:18).

1.4. Research questions. This study provides an acoustic description of Mundabli tones in terms of their fundamental frequency (f_0) and considers whether the laryngeal features of onset consonants affects the f_0 trajectories of the tones. We also investigate if the presence of tone and the complexity of the system of tonal contrast reduces the size of the f_0 perturbations which may be introduced by different onset types. Mundabli has a dense system of tone contrast (seven or eight tones) with high functional load, making it a good test case for whether the presence, contrast structure, and function of tone in a language can possibly constrain onset-f_0 effects. Reduced effects might be expected if onset-f_0 effects are not purely automatic and can be controlled by speakers under pressure to maintain tone distinctions.

2. Methods. Four speakers (2F, 2M) were recorded with a Zoom H4n recorder, using two Shure SM10A dynamic headset microphones, at a sampling rate of 44.1 kHz. Data collection was cen-

Tone name	Abbreviation	Example	Gloss
super-high	S	kű	'belly'
high	H	kú	'(at) home'
mid	M	kū	'ratmole'
low	L	kù	'rope'
high-mid	HM	kɔ́ɔ̄	'wisdom'
high-low	HL	kɔ̂p	'cup' (Eng. loan)
mid-low	ML	kūù	'clap' (clause-final)
low-high	LH	kɔ̌	'catch' (perfective)

Table 1. Examples of Mundabli tones on monosyllabic words (Voll 2017). Doubled vowels support multiple tone diacritics and do not indicate vowel length.

tered around lexical and grammatical elicitation. Multiple sessions were carried out near the city of Douala, Cameroon, in 2022 over the course of roughly one week. Although the recording site is distant from Lower Fungom, all participating speakers report regular use of Mundabli in the home and with other speakers in public in Douala; self-reported fluency and comfort with use of the language was high for all participants. All participants gave oral consent prior to study procedures and were compensated for their time and effort. Research procedures were approved by the University at Buffalo Institutional Review Board.

Recordings were transcribed and manually segmented using Praat TextGrids (Boersma & Weenink 2024), yielding a total of 4,667 word tokens. To ensure a roughly comparable prosodic context for the analyzed materials, target syllables were defined as stem-initial syllables in non-reduplicated verb and noun stems. The f_0 trajectory for each target vowel was extracted as a time series of 21 equidistant time points over each vowel's duration using PraatSauce (Kirby 2019) with default parameters. These time series effectively normalize for vowel duration, ensuring that f_0 trajectories can be compared across tokens with varying durations.

Because the dynamic nature of the onset-f_0 effect is not clear in advance, we used AR1 GAMMs (generalized additive mixed models; Sóskuthy 2017) to model the time-varying, potentially non-linear effects of onset voicing on the f_0 trajectory. A pooled model including data from all tonemes was fit, along with separate models for the data for each toneme (See Table 2 for detailed statistics) using the `bam()` function in *mgcv* (version 1.9.1) in R (R version 4.4.0).

Toneme	Token count	Toneme	Token count
L	906	LH	456
M	937	ML	1,001
H	625	HM	184
S	546	HL	12
Total level	3,014	Total contour	1,653

Table 2. Token count per toneme in the analyzed data.

Each model included a parametric smooth (m=1, k=5) for onset type (voiced obstruent, voiceless obstruent, sonorant), using thin plate regression splines to capture potentially non-linear effects in f_0 over time. In addition, factor smooths (m=1, k=5) for speaker and word were in-

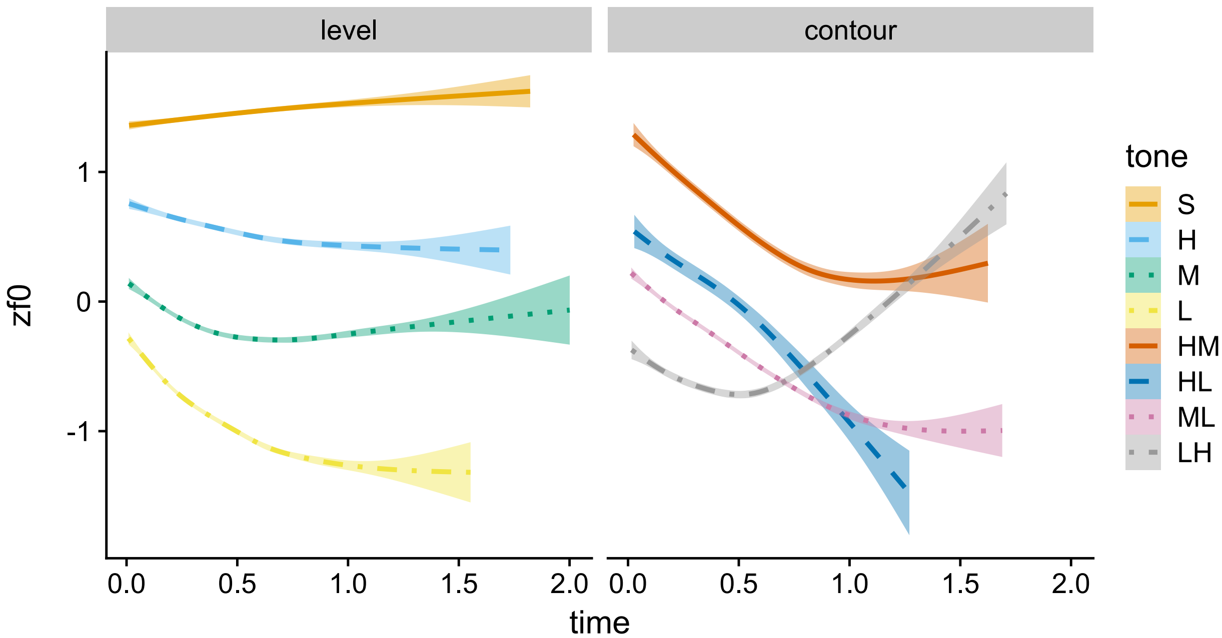

Figure 2. Trajectories of z-scored f_0 for level tones (left) and contour tones (right), with 95% confidence intervals. Smooths were estimated using *ggplot2*'s `stat_smooth(method="gam")` in R.

cluded in each by-toneme model, and the model pooling all tonemes inclued an additional factor smooth for tone category. Difference plots for each GAMM (excluding random effects) were generated as a means of visually demonstrating where the f_0 trajectories for different onset types reached a difference significantly greater than zero.

3. Results.

3.1. f_0 TRAJECTORIES BY TONE. Before discussing the modeled data in detail, we provide a general characterization of the typical f_0 contours of each toneme, as a basis for assessing their phonetic distinctiveness and potential overlap with one another. We separate the tones into level and contour tones for easier interpretability. Smoothed f_0 trajectories (Figure 2) indicate that the super-high (S), high (H), and mid (M) tones are roughly level as expected; all tones below the S tone have a tendency to slightly descend, and the low (L) tone has a more sharply descending f_0 than the other level tones. The contour tones also broadly correspond to their impressionistic descriptions, with some minor exceptions.

A fairly close similarity can be observed between the HL and ML tones as reported in Voll (2017:18), which may indicate that the few identified tokens of the HL tone are actually tokens of the ML tone. The high-mid (HM) and mid-low (ML) tones tend to rise slightly towards the end, and the lone rising low-high contour (LH) shows a clear f_0 drop before its expected rise begins. Whether these extra inflections are actually part of the tonemes' production targets (i.e. whether the HM or LH tones could be treated as "dipping" tones) is not clear given the lack of prosodic control around the analyzed tones, and we reserve this question for later study.

We observe that many tone pairs, particularly pairs of level tones and falling contours such

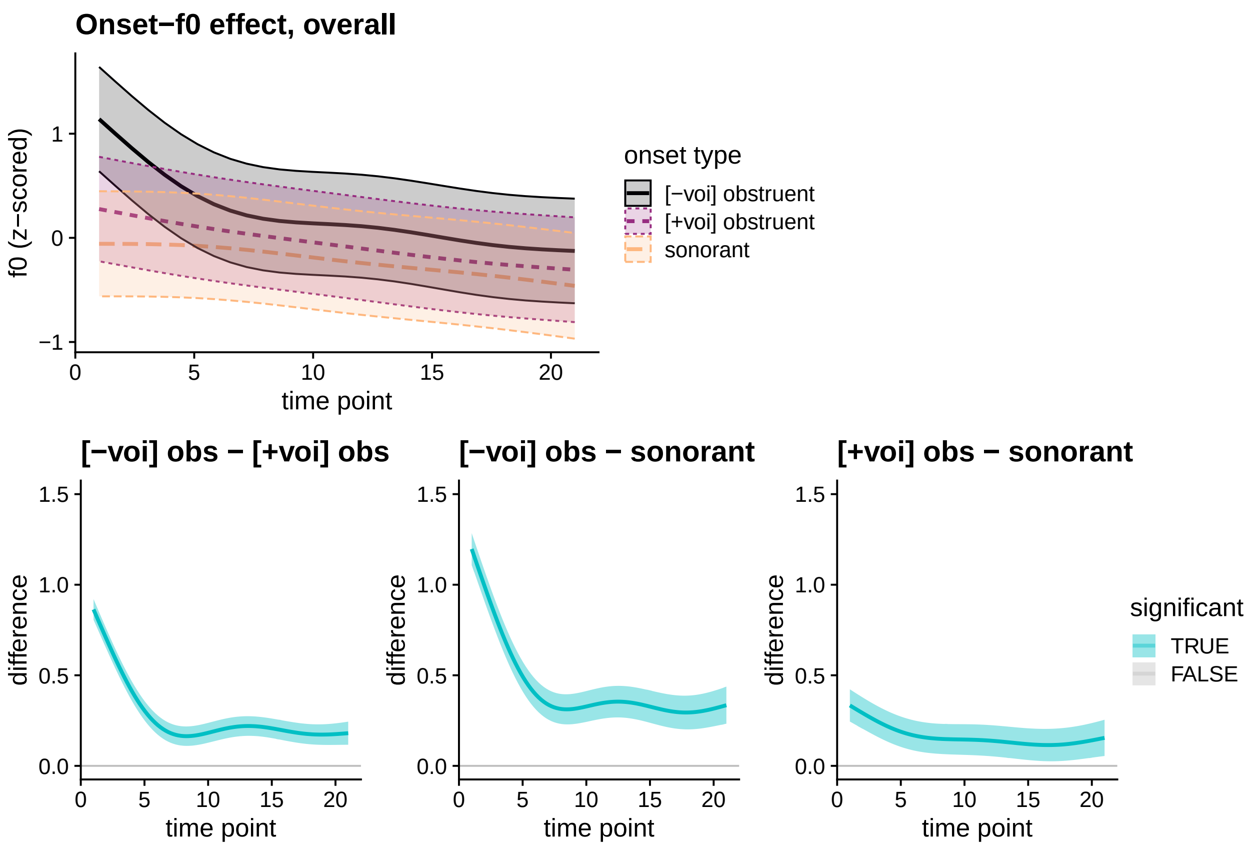

Figure 3. GAMM smooths (top) and difference smooths (bottom) for z-scored f_0 trajectories.

as the H and HM tones or L and ML tones, have the potential to be confusible with one another based on relatively close acoustic similarity in terms of f_0 trajectory. From this, it is reasonable to expect that any onset-f_0 effects present may increase the degree of overlap among some of these toneme pairs.

3.1.1. GAMM RESULTS, POOLED MODEL. Moving to the modeled data, we first consider the GAMM model that pools all tonemes together, in an effort to observe a tone-independent onset-f_0 effect if one is present. Figure 3 presents GAMM smooths by onset type (top) and difference smooths for all pairs of onset types (bottom) of z-scored f_0 for the full data set. These difference smooths provide significance estimates for the difference between each pair of trajectories. In discussing the pairwise differences between f_0 trajectories, we particularly focus on differences between obstruent onsets and sonorant onsets, since sonorants are often treated as a baseline for purposes of estimating onset-f_0 effects (Hanson 2009; Xu & Xu 2021).

Following voiceless obstruents, vowels begin with markedly elevated f_0 values, otherwise following a broadly similar but slightly elevated trajectory compared to the other two onset types. Voiced obstruents and sonorants start with lower f_0 values, with voiced obstruents' trajectory slightly elevated over sonorants' at a consistent level over the whole duration of the vowel. Significant differences are observed in all three pairwise comparisons of onset types. Voiceless obstruent onsets show a significant elevation of f_0 early in the vowel over both voiced obstruent and

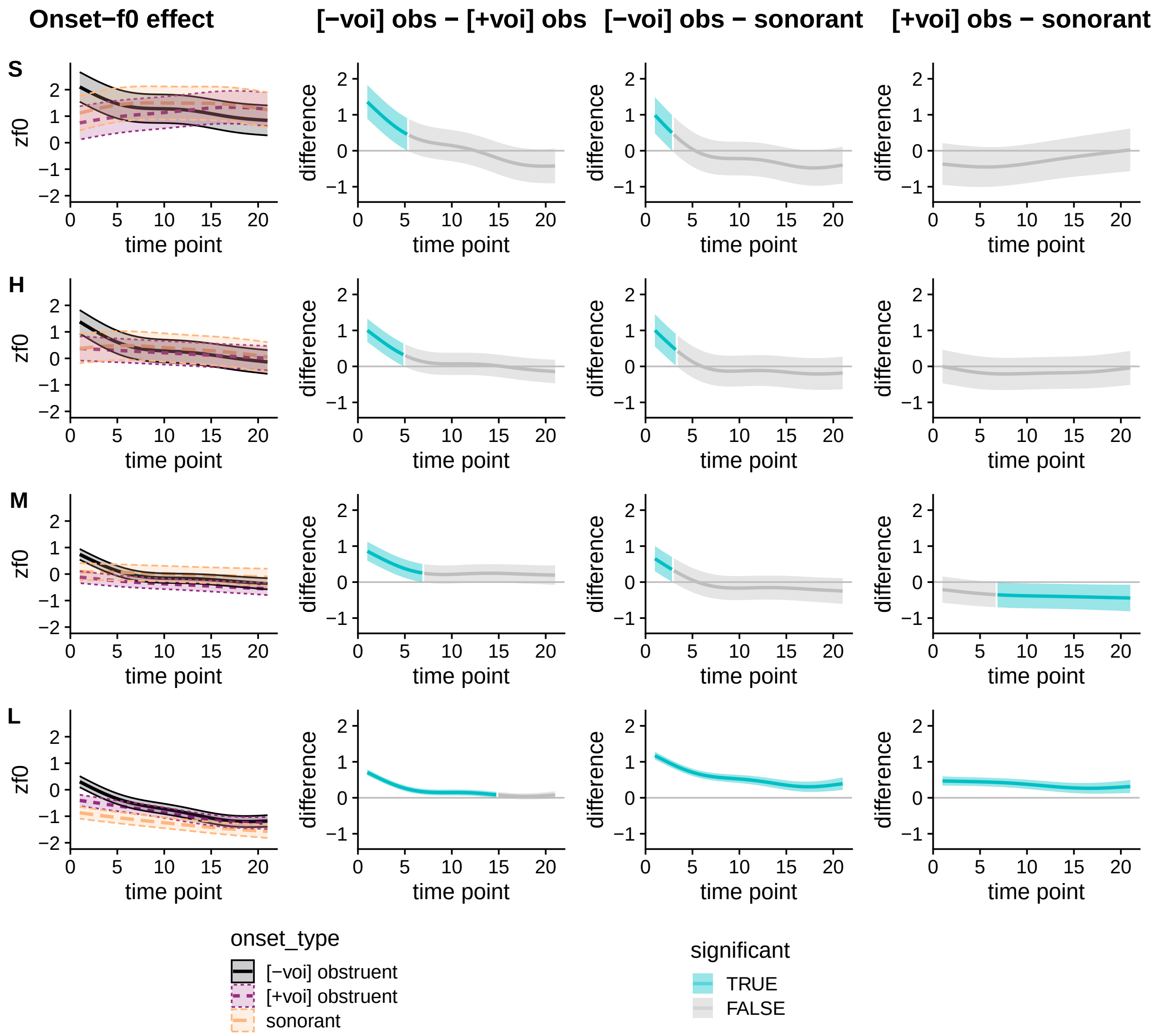

Figure 4. GAMM smooths (leftmost column) and difference smooths (right) for z-scored f_0 trajectories of level tones. The data for each tone (labels at left) occupies one row of four plots.

sonorant onsets, and a lower elevation over the remainder of vowels' duration. Voiced obstruent onsets also show a weakly significant elevation over sonorants which extends over the duration of the entire vowel.

3.1.2. GAMM RESULTS, INDIVIDUAL TONE MODELS. Figures 4 and 5 show GAMM results for individual toneme data, for level tones and contour tones, respectively. The high-low (HL) contour tone is omitted due to a low token count and the unresolved possibility that it is not distinct from either the ML contour tone. As we can see from these figures, the voicing of the initial consonant affects the f_0 trajectory in the first 5–10% of the duration of most tones. In addition, the patterns shown in these figures also vary depending on the specific tone category.

All tones exhibit the same elevated f_0 observed in the pooled model at the beginning of vow-

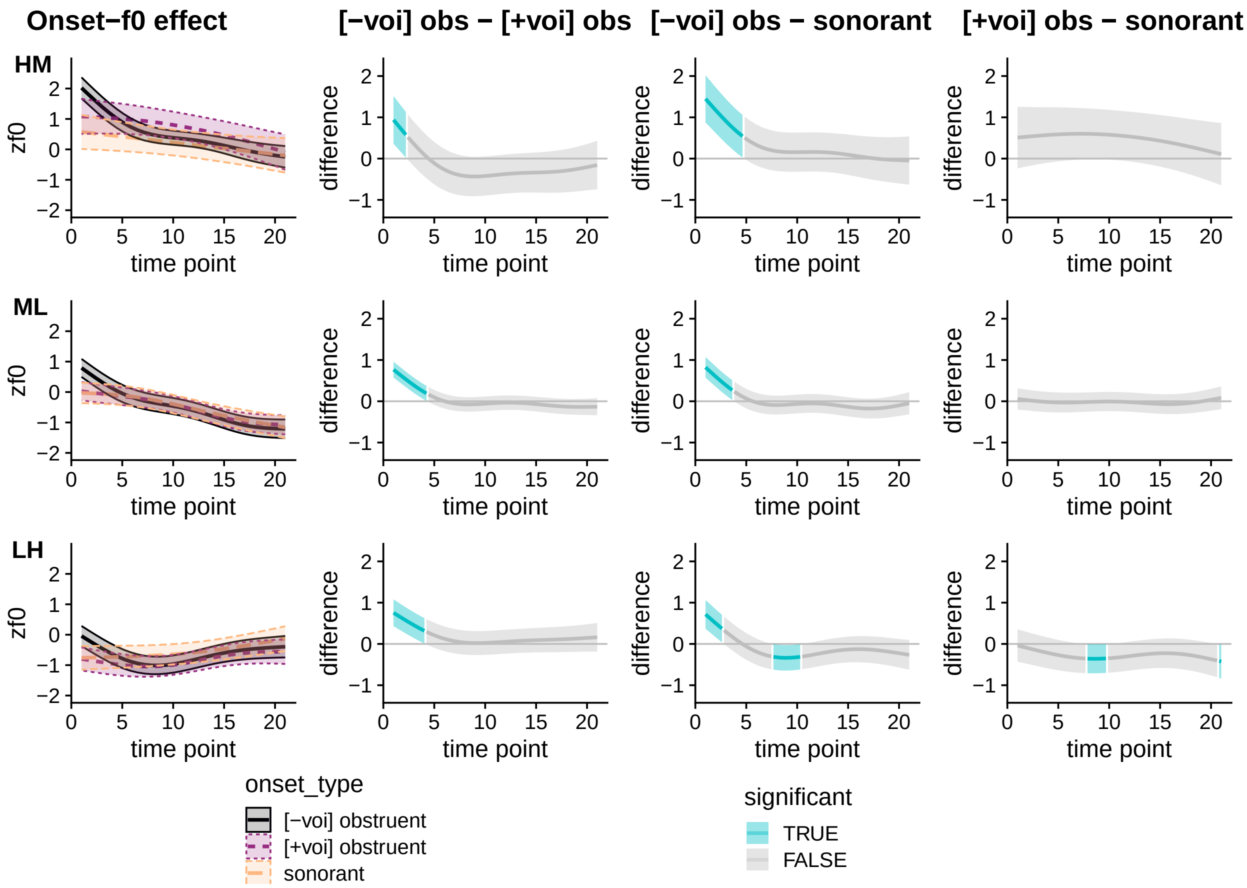

Figure 5. GAMM smooths (leftmost column) and difference smooths (right) for z-scored f_0 trajectories of contour tones. The data for each tone (labels at left) occupies one row of four plots.

els following voiceless obstruent onsets. This difference is observed consistently relative to both voiced obstruent and sonorant onsets. There is a tendency for lower tones to exhibit this difference over a greater temporal extent than for higher tones, most strikingly in the case of the low (L) tone, which uniquely shows significant differences of this sort across its entire duration. The difference between voiced obstruent onsets and sonorants, shown in the rightmost columns of Figures 4–5, is irregular and occasionally exhibits reversals relative to the overall effect in individual tones, most extensively in the case of the mid (M) tone.

4. Discussion.

4.1. Summary of findings. This study provides an in-depth acoustic analysis of Mundabli's dense tonal system, which can be confirmed to broadly follow the prior impressionistic work in Voll (2017). All tones show the expected patterns and appear acoustically distinct, except for the high-low (HL) contour tone. The observed tokens of HL may in fact be identifiable with the ML tone based on especially close similarity in the f_0 trajectories of these categories. Further investigation may be needed to confirm that these tonemes are distinct.

This study examined the effects of different types of onset consonants on tone production.

We found that vowels that follow voiceless obstruents begin with a significantly higher f_0, which remains slightly elevated throughout the vowel. In contrast, vowels following voiced obstruents and sonorants start with lower f_0 values, with voiced obstruents showing a modest but consistent elevation over sonorants. All three onset types show significant differences in pairwise comparisons, especially in the early part of the vowel. The strongest effect is the early f_0 rise after voiceless obstruents, while voiced obstruents show a weaker, sustained elevation relative to sonorants.

A standard account of onset-f_0 effects holds that voiceless obstruents condition a raised f_0 contour and voiced obstruents condition a lowered f_0 contour (Hombert 1978; Gao & Kirby 2024), due to automatic physiological factors in the production of voiced obstruents (Honda 2004; Moisik 2013). We note that the Mundabli data are inconsistent with this account. Instead, it aligns with the observation of several studies that there is no detectable *lowering* of f_0 associated with voiced obstruent consonants (Hanson 2009; Kirby & Ladd 2016). This in turn is consistent with the idea that some f_0 adjustments may be learned and controlled, rather than purely automatic (Kingston & Diehl 1994). The unusual nature of the observed adjustment for voiced obstruents in Mundabli – a slight elevation of f_0 rather than the lowering that might be expected – merits further investigation, if it is indeed an actual controlled effect rather than a spurious finding.

4.2. TONE AND CONSTRAINTS ON ONSET-f_0 EFFECTS. Our findings clearly show that onset-f_0 effects and contrastive tone co-exist in Mundabli, in spite of predictions of prior literature such as Hombert (1978). The raising effect of voiceless obstruents is present in all tones to a roughly similar extent, though there is a longer temporal extent of the effect in the L tone. The fact that onset-f0 effects are generally restricted to the early part of each tone's realization, with the exception of the L tone, may be significant: it is possible that the effect is, in fact, constrained to a restricted portion of the f_0 trajectory to preserve most of its duration for cuing tone categories. This framing is admittedly speculative without comparative evidence on the temporal extent of f_0 raising associated with voiceless obstruents in non-tonal languages. However, it suggests potentially fruitful directions for future research.

4.3. TONE INVENTORY DENSITY AND CONSTRAINTS ON ONSET-f_0 EFFECTS. This study also aimed to address the research question of whether the number of tonal contrasts in Mundabli poses any additional constraints on onset-f_0 effects. Because evidence suggests that tone, in and of itself, does not impose any overall constraints on onset-f_0 effects, we focus on specific tones that show behaviors distinct from the others. It stands to reason that the behavior of the L tone is connected to its lack of close competitors. The onset-f_0 effect is quite short for most of the tones, with the exception of the L tone, which has significant effects throughout nearly its whole time course. The L tone is also rather well separated from potential competitors such as the level M tone and the ML contour tone in terms of its steep trajectory, relatively short duration, and low overall f_0 (Figure 2).

We might expect tones with few or more distant competitors to permit more category-internal variation due to the onset-f_0 effect, given that variation is expected to be constrained only if relevant to specific contrasts (Hauser 2021). In this view, the expanded temporal extent of the onset effect in the L tone may reflect its relative perceptual security within Mundabli's tonal space, allowing for greater phonetic flexibility without risking confusion. This possibility raises broader questions about how contrastive pressures shape the realization of tonal cues across languages. Future research may further explore the relationship between tonal inventory size and onset effects in other languages with dense tonal inventories to explore if these findings are language-universal.

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