

## Tonal Alignment Contrasts Falling Tones in Feixiang Chinese

**Introduction.** This study investigates which acoustic correlate contrasts the two lexical falling tones (Fall 1 and Fall 2) in Feixiang Chinese (FC), a variety of Jin Chinese (中国社会科学院语言研究所 et al., 2012). Traditional analyses often assume that tones with the same contour shape (e.g., falling) differ primarily in tone level (He, 1986; Yip, 2002). More recent work, however, suggests that tonal alignment—the timing of tonal target realization—is the primary contrastive feature for such tones (e.g., Remijsen & Ayoker, 2014; DiCano et al., 2014; Gussenhoven & van de Ven, 2020). In addition, prior analyses have often failed to account for correlations among acoustic features or have treated tone category as the predictor rather than the outcome variable (e.g., Remijsen, 2013; Chen, 2022; Author, 2026). Accordingly, this study addresses:

1. Which acoustic feature plays the key role in distinguishing the two falling tones in FC?
2. Which types of data analysis are best suited to addressing this type of question?

**Method.** The stimuli consisted of 25 monosyllabic falling-tone minimal pairs. Six native speakers recorded the items at home using phones and head-mounted microphones. Each  $F_0$  contour was represented by 40 time-normalized  $F_0$  values (in semitones) and z-transformed by speaker. From each contour, the following acoustic features were extracted:  $F_0$  maximum (Max), timing of the maximum (MaxTime), minimum (Min), range, slope, curvature, and duration. After excluding 25 productions due to mispronunciations or recording issues, 275 tokens remained (Fall 1: 147; Fall 2: 128).

**Data Analysis.** Correlations among the acoustic features were examined. To facilitate comparison with previous univariate analyses, a Bayesian multivariate mixed effects regression model was fitted with the features selected based on the correlation structure as outcome variables (Listing 1). Second, given the goal of identifying which feature most strongly distinguishes tone categories, a logistic mixed effects regression model was fitted with Tone as the outcome variable (Listing 2).

**Result.** Correlations of varying strength were observed among the acoustic features (Figure 1). Based on this structure, Min was selected to represent the highly correlated contour features, MaxTime the time-related features, and Max was retained due to its moderate correlations with other variables.

The multivariate regression results (Table 1) revealed a robust effect of tone category on the realization of the falling tones, with the strongest effect on MaxTime ( $\beta = 0.98$ ), indicating a later-aligned  $F_0$  peak for Fall 2, a moderate effect on Min ( $\beta = 0.63$ ), and a weaker effect on Max ( $\beta = -0.27$ ).

In the mixed logistic regression analysis (Table 2), MaxTime had the strongest effect ( $\beta = 4.47$ ), indicating that later-aligned  $F_0$  maxima increased the likelihood of a Fall 2 classification. Min showed a positive effect ( $\beta = 1.75$ ), whereas Max had a negative effect ( $\beta = -1.23$ ). A significant interaction between Min and Max ( $\beta = 0.73$ ; Figure 2) indicates that the effect of  $F_0$  minimum depends on the level of  $F_0$  maximum.

**Discussion.** Consistent with prior studies, this study provides acoustic evidence that tonal alignment is the contrastive feature for FC falling tones. Unlike them, it also shows that  $F_0$  maximum and minimum contribute to and interact in distinguishing the two falling tones. This new finding is thanks to the data-analytic approach adopted in this study, which explicitly addresses correlations among acoustic features and treats tone category as the outcome variable.

## References

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## Appendix

Listing 1: The Bayesian mixed-effects multivariate model.

```
1 mv_max <- bf(mvbind(Max_z) ~ Tone +
2             (1 |p|Speaker) + (1 |q| Syllable)) + skew_normal()
3 mv_min <- bf(mvbind(Min_z) ~ Tone +
4             (1 |p|Speaker) + (1 |q| Syllable)) + student()
5 mv_max_time <- bf(mvbind(MaxTime_z) ~ Tone +
6                 (1 |p|Speaker) + (1 |q| Syllable)) + skew_normal()
7
8 fit_mv <- brm(
9   formula = mv_max + mv_min + mv_max_time + set_rescor(FALSE),
10  data = data,
11  cores = 4,
12  iter = 4000,
13  control = list(adapt_delta = 0.99),
14  seed = 3749
15 )
```

Listing 2: The mixed-effects logistic regression model.

```

1 logit_formula <- Tone ~ 1 +
2   MaxTime_z + Min_z + Max_z +
3   Min_z:Max_z +
4   (1 | Syllable) + (1 | Speaker)
5
6 logit_model <- glmer(
7   formula = logit_formula ,
8   data    = data ,
9   family  = binomial(link = "logit"),
10  control = glmerControl(
11    optimizer = "bobyqa",
12    optCtrl   = list(maxfun = 1e5)
13  )
14 )

```

Table 1: Fixed effects from the multivariate Bayesian regression model (95% CrI).

Term	Estimate	SE	2.5%	97.5%
Max_z_Intercept	0.102	0.324	-0.546	0.749
Min_z_Intercept	-0.276	0.421	-1.159	0.581
MaxTime_z_Intercept	-0.508	0.329	-1.186	0.149
Max_z_Tonefall2	-0.269	0.104	-0.467	-0.063
Min_z_Tonefall2	0.628	0.085	0.463	0.793
MaxTime_z_Tonefall2	0.984	0.069	0.854	1.119

Table 2: Fixed effects from the mixed logistic regression model.

Term	Estimate	SE	$z$	$p$
(Intercept)	0.297	0.655	0.45	0.6501
MaxTime_z	4.472	0.695	6.44	<0.001
Min_z	1.750	0.392	4.46	<0.001
Max_z	-1.230	0.356	-3.46	<0.001
Min_z:Max_z	0.726	0.342	2.12	0.0339

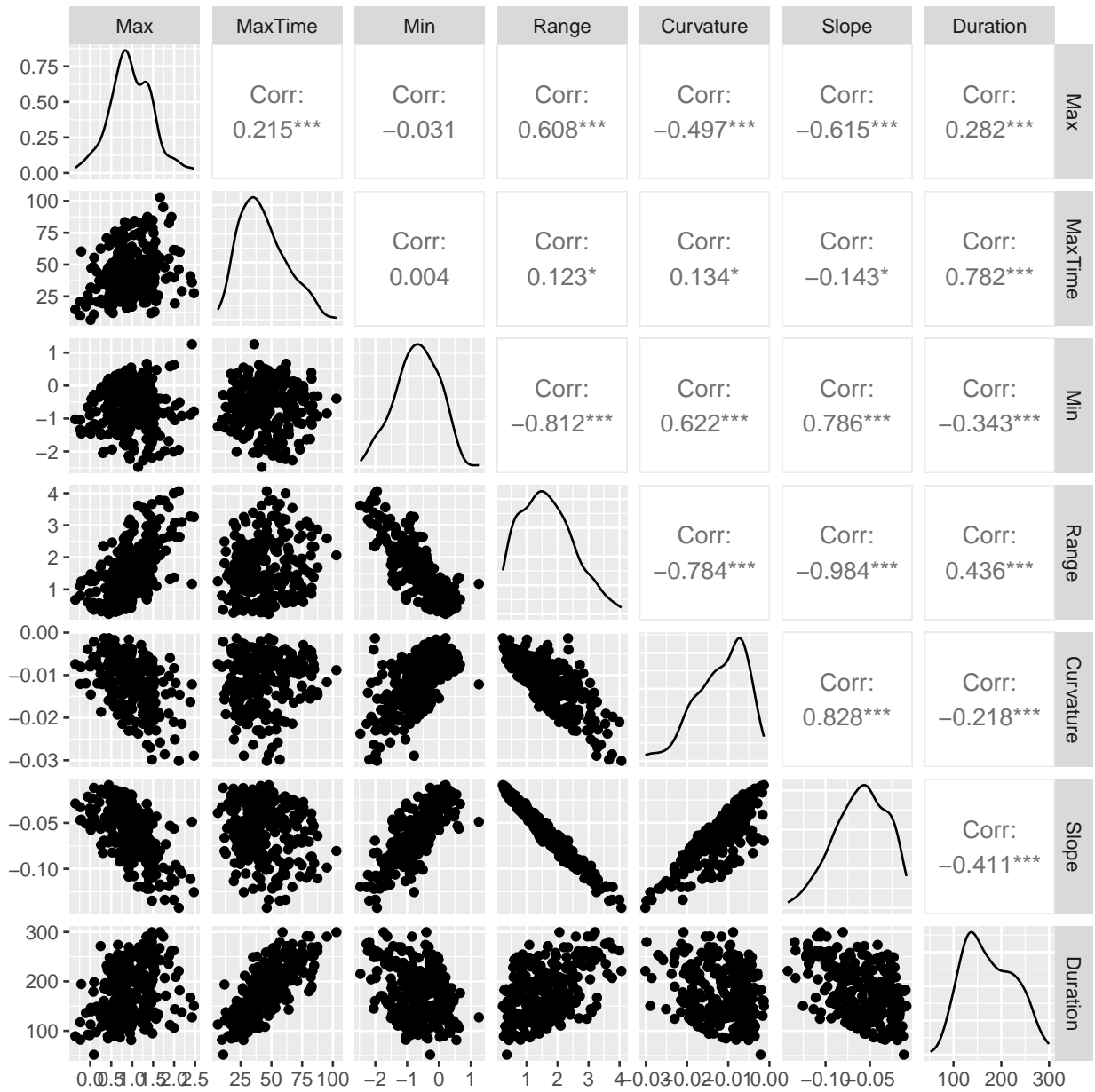


Figure 1: Pairwise correlations among the acoustic features

### Interaction: F0 minimum vs F0 maximum (both scaled)

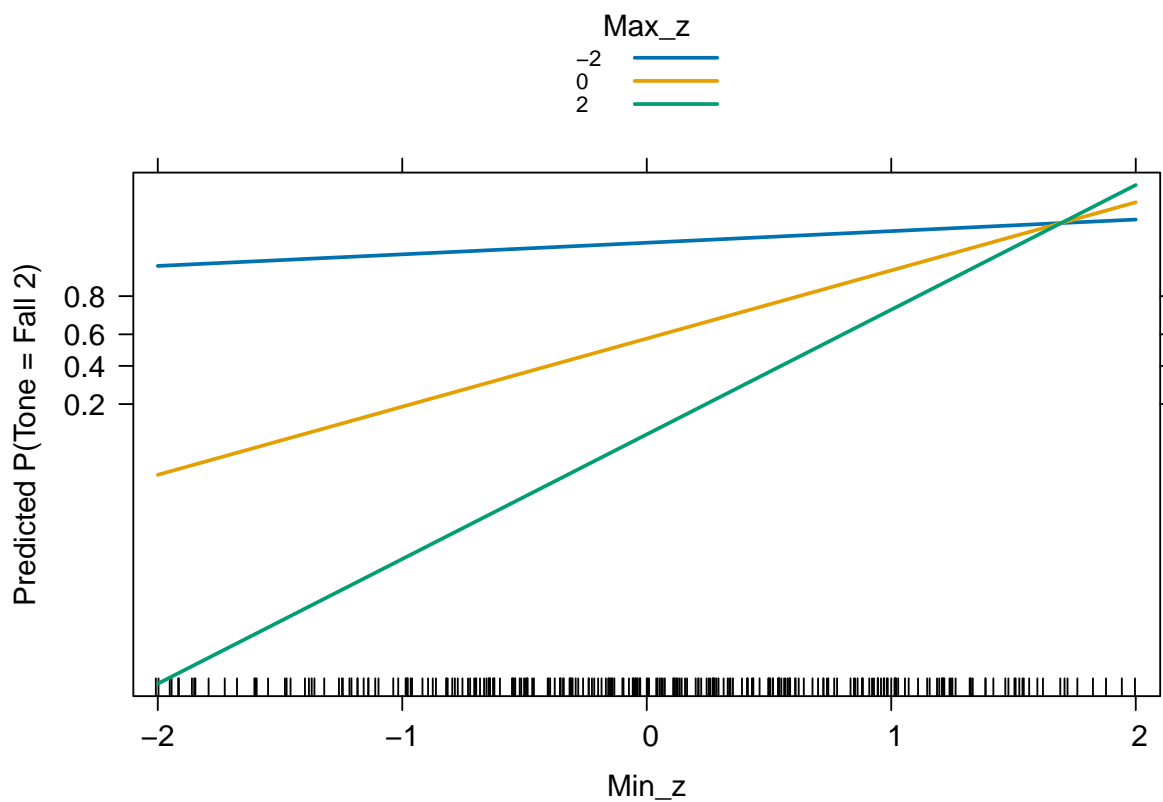


Figure 2: Interaction: F0 minimum vs F0 maximum (both scaled)