

Equilibrium Dynamics of Near-Merger: Functional Load Effects in Cantonese Tone Contrast

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1. Research Problem

Near-merger creates a puzzle for sound change: speakers may maintain a small production difference while failing to sustain the same contrast perceptually.

- **Asymmetry:** why can perception move toward merger faster than production?
- **Lexical structure:** when does functional load protect a contrast from merger?
- **Equilibrium:** can a weak contrast persist as a stable state, rather than as a residue on the way to complete merger?

Goal: model near-merger as a locally stable dynamical outcome. The question is not only whether T2–T5 merges, but which stable states are made available by lexical structure and functional load.

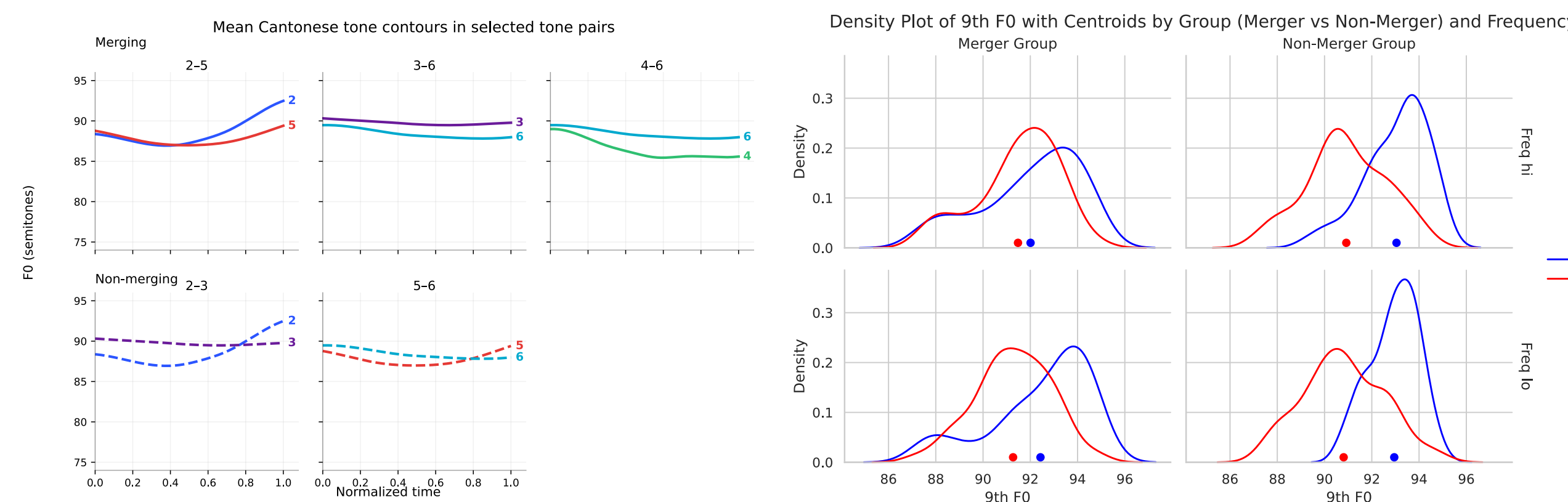
2. Cantonese T2–T5 as a Test Case

Hong Kong Cantonese has six lexical tones. T2 and T5 are both rising tones, and differ most clearly near the contour offset: T2 reaches a higher final F0 than T5.

- **Empirical pattern:** T2–T5 is undergoing merger for some speakers, but non-merging speakers still show a small offset difference.
- **Local cue:** the modeled dimension is late-contour F0, especially the ninth normalized F0 point where the offset-region separation is clearest.
- **Why diagnostic:** the contrast is small, prosodically structured, and located in a crowded region of the tonal space.

3. Empirical Starting Point

The model is initialized from non-merging speakers in Mok et al. (2013). Their monosyllabic productions provide the closest available approximation to a shared pre-merger T2–T5 representation.



- **Non-merger baseline:** T2 is centered higher than T5 in the late-contour region, giving the model its initial category separation.
- **Merger comparison:** the same tones overlap more strongly, motivating a model of gradual compression rather than abrupt category loss.
- **Emergent mismatch:** production and perception start from the same distributions, so later mismatch is not built into the initial state.

Data-to-Model Mapping

The empirical plot is used to define the starting state and the target phenomenon, not to fit a separate classifier.

- **State variable:** each exemplar stores a scalar late-contour F0 value x and a memory weight w .
- **Initialization:** production and perception start identical, seeded from non-merging speakers.
- **Outcome to explain:** the merger group motivates increased distributional overlap without assuming that tone categories disappear.
- **Lexical unit:** the toy lexicon manipulates competitor structure while holding the number of pairable lexical materials constant.

Model Scope and Assumptions

The model isolates the local T2–T5 cue rather than reducing the full Cantonese tone system to one dimension. Perception is modeled narrowly as categorization over exemplar distributions, abstracting away from socioindexical, lexical-contextual, and multimodal information.

- **Cue tracked:** offset-region F0, the most direct local cue to the T2–T5 contrast.
- **Memory:** old exemplars decay; new tokens update bounded lexeme-specific stores.
- **Functional load:** local minimal-pair support, not global entropy of the whole tone system.

Empirical Anchor

- **Contour-level cue:** the T2–T5 contrast is concentrated near the offset, where T2 reaches a higher final F0 than T5.
- **Model dimension:** the density plot turns that local cue into a scalar late-contour F0 state variable.
- **Model target:** non-merging productions define the initial contrast; merger data define the outcome to explain: greater overlap without assuming category deletion.

4. Central Claim

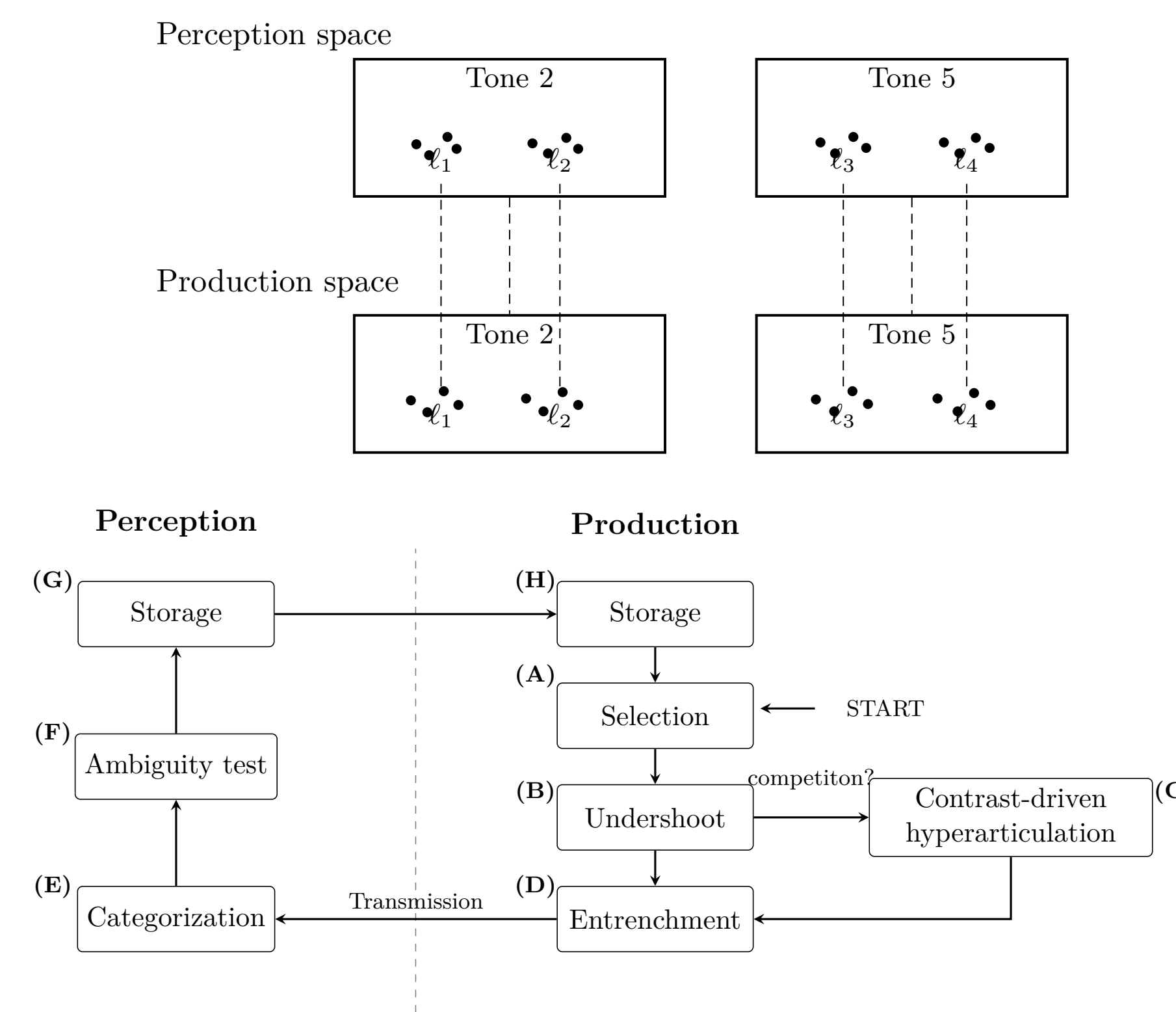
Near-merger can be a **locally stable equilibrium**: production retains a residual contrast because lexical competition protects some tokens, while perception collapses more readily because ambiguous tokens accumulate across category boundaries.

phonetic reduction + lexical support + asymmetric updating
⇒ near-merger

Near-merger is emergent: production and perception begin aligned, then diverge because the same token has different storage consequences across domains. Reduction pulls categories inward; minimal-pair protection pushes selected productions apart; ambiguous storage compresses perception.

5. Exemplar Production–Perception Loop

Production and perception begin from the same category, lexeme, and exemplar structure, but are stored in separate representational spaces. Divergence emerges from the update cycle rather than being stipulated in advance.



- **Initialization:** corresponding lexical items occupy parallel positions in production and perception.
- **Token cycle:** lexeme selection → exemplar sampling → undershoot → lexical contrast protection → perceptual categorization.
- **Same token, different storage:** perception stores ambiguity; production stores lexical intent.

Asymmetric Storage Creates Mismatch

In perception, a token that receives similar support from T2 and T5 is stored in both categories. Repeated ambiguous storage pulls perceptual categories toward each other. In production, the same token is written back only to the intended lexeme after lexical recovery.

$$P(c | x) = \frac{S_c(x)}{S_2(x) + S_5(x)}, \quad |P(2 | x) - P(5 | x)| \leq \delta.$$

- **Perception:** ambiguous → T2 and T5 stores.
- **Production:** recovered lexeme → intended store only.
- **Consequence:** perception can collapse before production loses its lexically supported residue.

6. Functional Load Mechanism

Functional load is operationalized as the proportion of lexical materials that remain T2–T5 minimal-pair competitors. Doublets receive contrastive protection; singletons are freer to reduce:

$$\pi_{mp} = \frac{\text{minimal-pair materials}}{\text{pairable lexical materials}}.$$

Production-side equilibrium distance is:

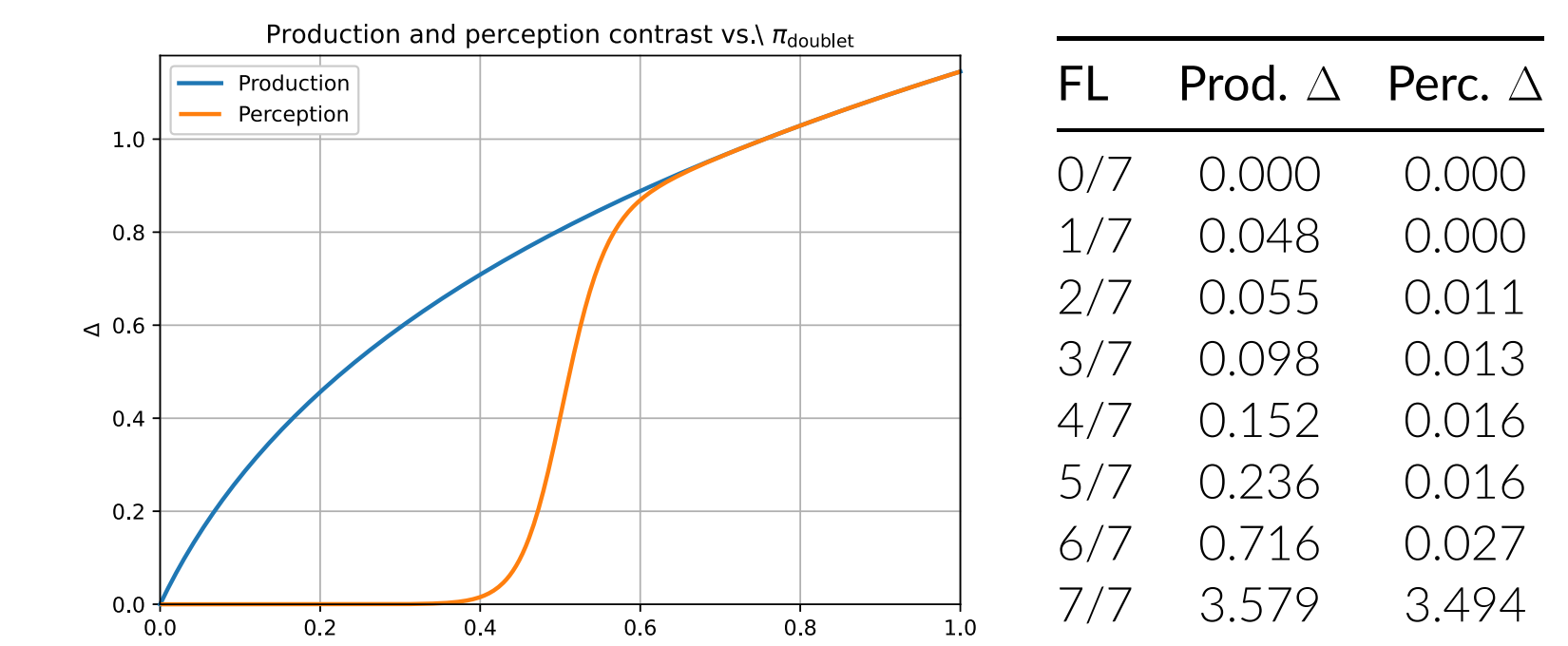
$$\Delta_{prod}^* = A\pi_{mp}e^{-\lambda\Delta_{prod}}.$$

The simulations vary support from 0/7 to 7/7 pairable materials while keeping lexicon size constant. For example, 1/7 means one surviving T2–T5 minimal pair, or two contrastive words out of fourteen total words.

- **High π_{mp} :** more tokens receive contrast-enhancing pressure from surviving minimal-pair competitors.
- **Low π_{mp} :** more words behave as singletons and can undergo undershoot without lexical competition.
- **Attractor control:** FL changes the stable target, not only the speed of change.
- If $\pi_{mp} \rightarrow 0$, production equilibrium collapses toward merger.

7. Results: Production and Perception Diverge

The model predicts a broad intermediate region where production separation remains positive but perception is near zero.

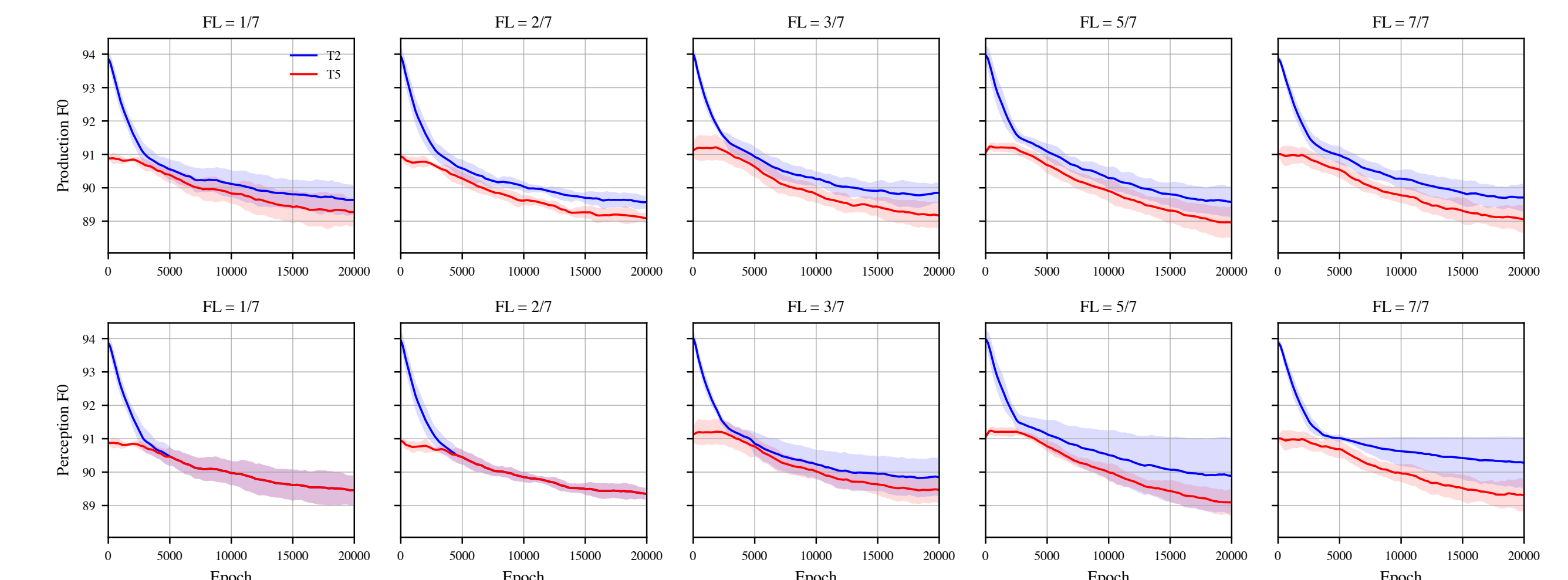


The diagnostic pattern is the gap between domains. From 1/7 through 6/7, production retains a positive residue while perception remains near zero. At 7/7, lexical support is strong enough to preserve both.

- **Low support:** both domains collapse, producing complete merger.
- **Intermediate support:** production remains positive while perception is near zero, the model's near-merger regime.
- **Full support:** lexical competition is strong enough to keep production and perception aligned.

The important result is not only that low-FL contrasts are more likely to merge. Reduced lexical support first produces **production–perception mismatch**: perception collapses before lexical support is weak enough to erase production structure.

8. Lexical Support Changes the Trajectory



Each column shows one lexical-support setting (1/7, 2/7, 3/7, 5/7, or 7/7); production trajectories are on the top row and perception trajectories are on the bottom. Blue and red curves track the four-seed mean for T2 and T5, with shaded bands showing one standard deviation.

Across conditions, both tones move downward under reduction pressure, but lexical support changes how much T2–T5 separation survives. Low-support lexicons approach overlap quickly, whereas higher-support lexicons retain a more visible gap through the 20,000-epoch window, especially in production.

- **Not a single path:** each loss of a minimal-pair relation changes the lexical landscape the system converges toward.
- **Intermediate support:** reduction and contrast maintenance compete long enough to produce a stable residue in production.
- **Why perception leads:** ambiguous perceptual storage keeps pooling T2 and T5 evidence even while lexical identity preserves some production separation.

9. Interpretation, Predictions, and Scope

- **Equilibrium, not midpoint:** changing functional load changes the stable target of the system, not only the speed of merger.
- **Near-merger diagnostic:** the relevant state is $\Delta_{prod} > 0$ with $\Delta_{perc} \approx 0$.
- **Empirical prediction:** the strongest speaker–listener mismatch should occur at intermediate lexical support, where the contrast is produced but weakly recoverable.
- **Mechanism:** ambiguous perception pools evidence across categories, while production can write tokens back to the intended lexeme after lexical recovery.
- **Lexical prediction:** words with surviving T2–T5 competitors should retain stronger production separation than singleton words.
- **Timing prediction:** perceptual confusability should increase before production distance fully disappears.
- **Transmission question:** if near-merger is a synchronic equilibrium, the next issue is whether weakly supported contrasts are acquired, neutralized further, or regularized by learners.
- **Critical empirical test:** compare production and perception in the same speakers while separating minimal-pair words from singleton words.
- **Model scope:** the simulation isolates offset-F0; frequency, social meaning, and multi-cue perception are left for extensions.

Selected references

Labov, Karen, and Miller (1991). *Language Variation and Change*, 3(1), 33–74; Mok, Zuo, and Wong (2013). *Language Variation and Change*, 25(3), 341–370; Pierrehumbert (2001). *In Frequency and the Emergence of Linguistic Structure*, 137–157; Wedel, Kaplan, and Jackson (2013). *Cognition*, 128(2), 179–186; Soo and Babel (2023). *Laboratory Phonology*, 14(1), 1–38.