

Equilibrium Dynamics of Near-Merger: Functional Load and Contrast Persistence

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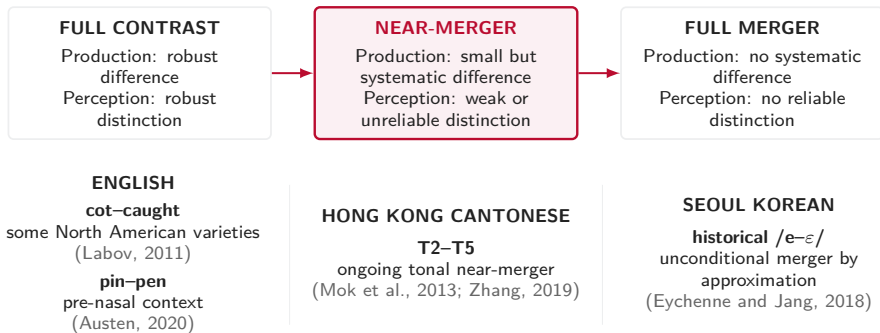


The Phenomenon: Near-merger

Production contrast without reliable perception

Near-merger: Speakers maintain a small, systematic production difference between historically distinct categories without a comparably robust perceptual distinction. (Labov et al., 1991; Hickey, 2008)

Conventional trajectory in neutralization



Near-merger is reported in segmental and tonal contrasts across languages.

Primary Question:

When does near-merger occur?

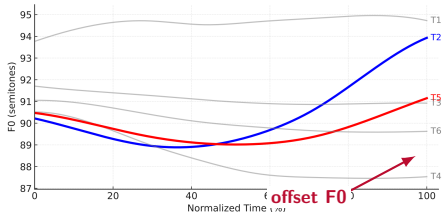
instead of interpreting it only as a transitional stage.

Further Question:

Under what **lexical** and **cognitive** circumstances does a phonological system stabilize as a near-merger rather than progressing to a full merger?

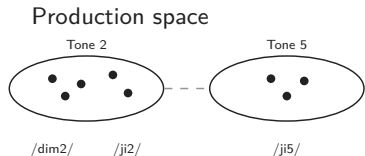
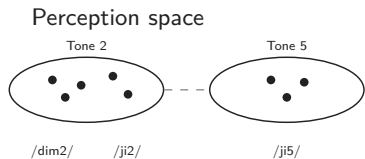
Hong Kong Cantonese T2–T5

- Hong Kong Cantonese has six lexical tones; T2 and T5 are both rising tones.
 - T2 reaches a higher offset F0 than T5.
 - The contrast is most visible near the end of the contour.
 - T2 and T5 are reported as merger-in-progress (Mok et al., 2013; Zhang, 2019; Ren and Mok, 2025).
- Modeling choice:
 - We isolate the offset-F0 cue.
 - This gives a simple one-dimensional phonetic space to manipulate.



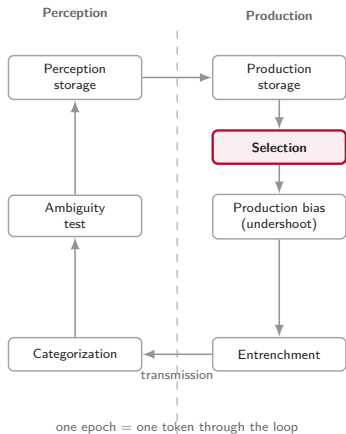
Model

Model Schema: representation

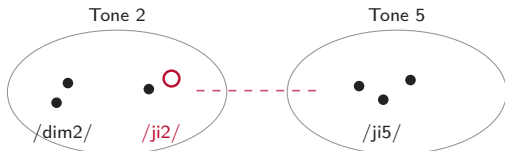


- Two separate exemplar spaces with interactions (Morley, 2023; Pinget, 2015)
- In each space, we define tonal categories (e.g., T2, T5), each represented by a cloud of exemplars in F0–time space.
- Within each tonal category, we define lexical subcategories:
 - F0 realizations of T2 and T5 non-merger speakers are mapped to words from Mok et al. (2013).
 - Some subcategories have counterparts in the other tone: doublets vs. singletons.

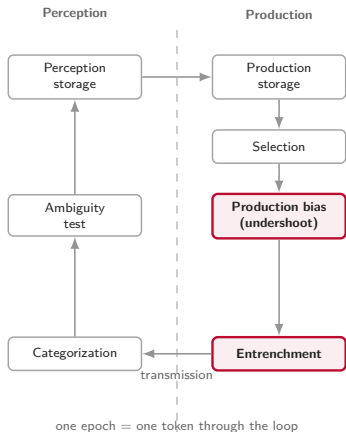
Model Schema: selection



- Each epoch starts by selecting one intended lexical item.
- A tone category and lexeme are chosen in the production store.
- One exemplar from that lexeme supplies the production target.
- Lexical identity is retained through the epoch, so production can later write the token back to the intended word.



Model Schema: production bias



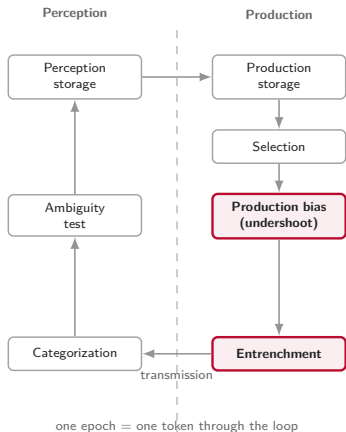
Undershoot

all selected tokens

$$x_c^{\text{und}}(t) = x_{\text{onset}} + (x_c^{\text{target}}(t) - x_{\text{onset}}) (1 - e^{-dk_c})$$

d = token duration; k_c = category-specific approximation rate
(Nagy et al., 2024; Ren and Mok, 2025)

Model Schema: production bias

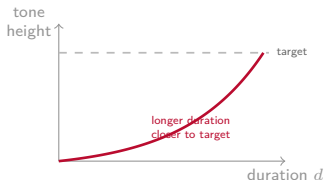


Undershoot

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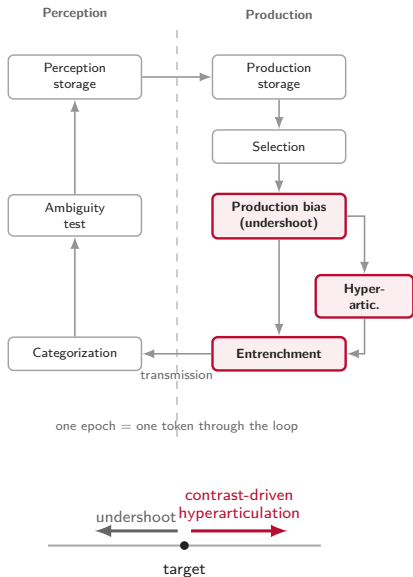
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Motivated by target approximation and reduced/fluent tonal realization (Xu and Wang, 2001).

Model Schema: production bias



Undershoot

all selected tokens

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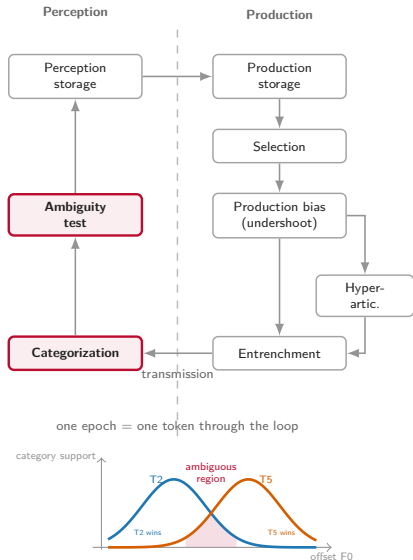
Hyperarticulation

doublets only

$$x_c^{\text{con}}(t) = x_c^{\text{und}}(t) + s_c \beta_{\text{max}} \times \exp\left(-\left|x_c^{\text{und}}(t) - \mu_{-c}^{\text{prod}}(t)\right|\right)$$

$s_2 = +1$, $s_5 = -1$
largest near the competitor mean; weaker farther away
(Lindblom, 1990; Wedel et al., 2018)

Model Schema: perception categorization and ambiguity



- **Perception simplified as categorization**

- Incoming tokens are evaluated against the perceptual exemplar space.

Gaussian-kernel classifier

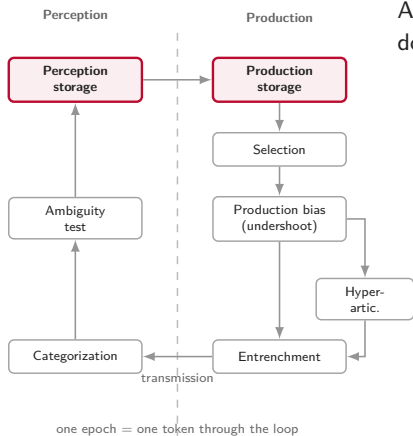
$$S_c(x) = \sum_{e_i \in E_c} \exp\left(-\frac{\|x - e_i\|^2}{2h^2}\right)$$

$$P(c|x) = \frac{S_c(x)}{S_{T2}(x) + S_{T5}(x)}$$

- **Ambiguity test**

- Compute posterior-like support for T2 vs. T5.
- Unambiguous: one category clearly wins.
- Ambiguous: $|P(T2|x) - P(T5|x)| \leq \delta$.

Model Schema: asymmetric storage



Ambiguous evidence is stored differently across domains.

- **Perception storage**

- Unambiguous token → winning category.
- Ambiguous token → both T2 and T5.
- Pooling pulls perceptual categories together.

- **Production storage**

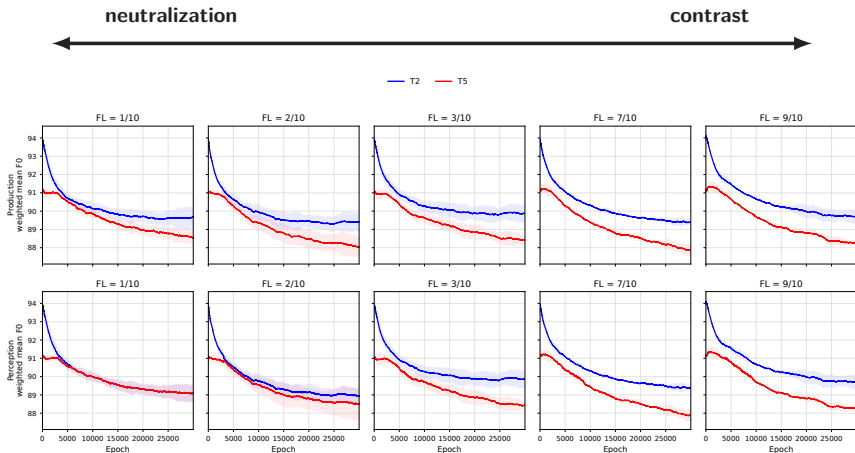
- Lexical recovery identifies the intended word.
- Token → intended lexeme / tone.

Now run the model!

- Functional load \approx doublet / minimal-pair count (Wedel et al., 2013)
 - More FL means more T2–T5 minimal pairs.
 - More minimal pairs trigger hyperarticulation more often.
- Toy lexicon manipulation
 - Start with 10 possible T2–T5 minimal pairs.
 - Create 11 scenarios: 0/10, 1/10, 2/10, ..., 10/10.
 - Total lexical materials stay constant; only competitor structure changes.
- Simulation design
 - Run each functional-load scenario 3 times.
 - Each run uses a different random seed.
 - Run until convergence, then compare production and perception separation.

Results

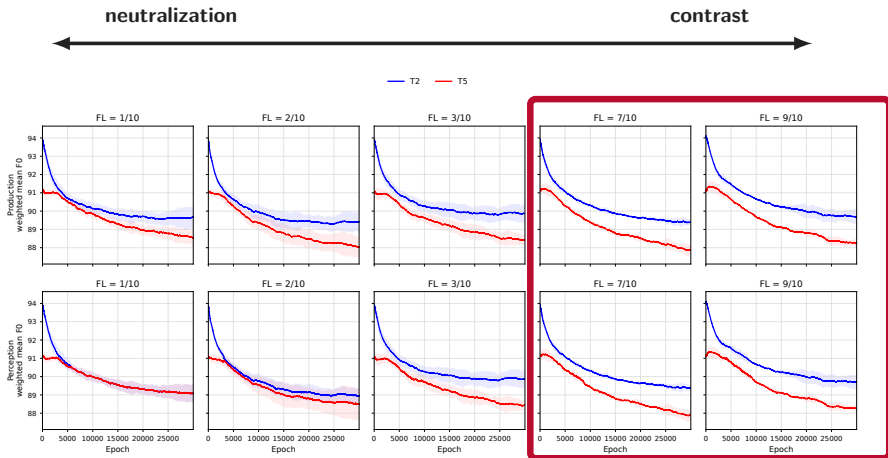
Result 1: Evolutionary Trajectory with Different Functional Load



The epoch trajectories show how T2 and T5 evolve under different functional-load conditions.

- First row: production; second row: perception.
- Three model runs are shown with different random seeds.

Result 1: Evolutionary Trajectory with Different Functional Load



The epoch trajectories show how T2 and T5 evolve under different functional-load conditions.

- **High FL:** production and perception converge stably; both domains preserve contrast.

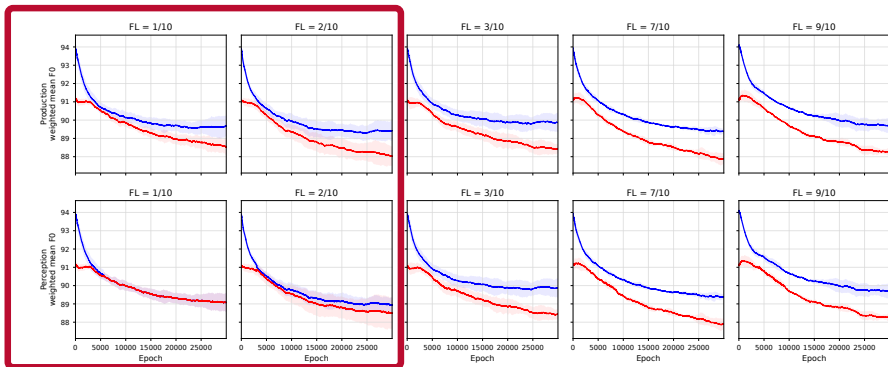
Result 1: Evolutionary Trajectory with Different Functional Load

neutralization

contrast



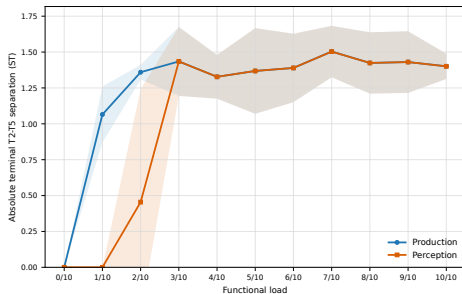
— T2 — T5



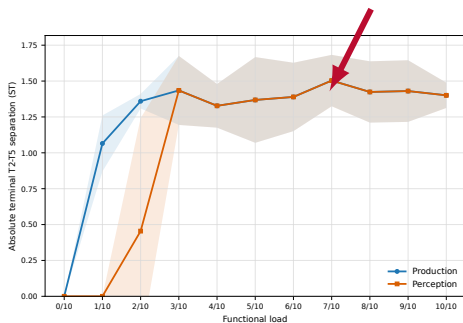
The epoch trajectories show how T2 and T5 evolve under different functional-load conditions.

- **High FL:** production and perception converge stably; both domains preserve contrast.
- **Low FL:** production preserves a residue, while perception merges T2 and T5.

Result 2: Stable States Across Functional Load

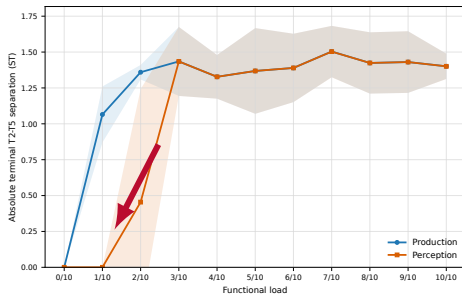


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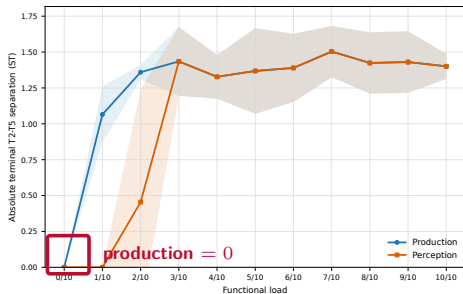
- **FL = 3/10+**: full contrast. Lexical support recovers stable perceptual separation.

Result 2: Stable States Across Functional Load



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- **FL = 1/10–2/10:** near-merger. $\Delta_{\text{prod}} > 0$, $\Delta_{\text{perc}} \approx 0$. Production retains residue; perception remains weak/variable.

Result 2: Stable States Across Functional Load



- **FL = 3/10+:** full contrast. Lexical support recovers stable perceptual separation.
- **FL = 1/10–2/10:** near-merger. $\Delta_{\text{prod}} > 0$, $\Delta_{\text{perc}} \approx 0$. Production retains residue; perception remains weak/variable.
- **FL = 0/10:** full merger. With no active minimal pairs, both domains collapse.

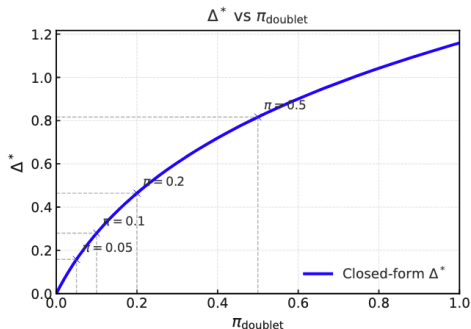
Result 3: Functional Load and Equilibrium Distance

Production-side equilibrium

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

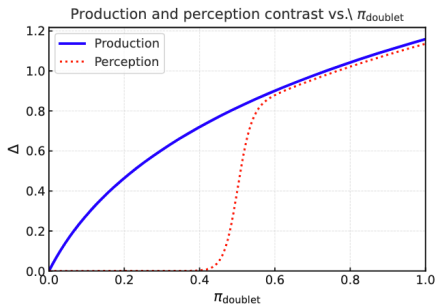
$$A = \beta_{\text{max}} \left(\frac{1}{\gamma_2} + \frac{1}{\gamma_5} \right), \quad \gamma_c = e^{-dk_c}$$

- A packages production-bias parameters:
 - hyperarticulation and production bias (undershoot).
- $\pi_{\text{mp}} = 0 \Rightarrow \Delta_{\text{prod}}^* = 0$.
- Larger π_{mp} supports a larger residual production gap.



Analytical production equilibrium under the current model setting.

Result 3: Functional Load and Equilibrium Distance



- The full model is run across the same functional-load scenarios.
- Perception is evaluated by simulation because ambiguous tokens can pool across T2 and T5.
- The perception transition appears as an S-shaped / threshold-like curve across functional load.

Near-merger diagnostic:

$$\Delta_{\text{prod}}^* > 0, \quad \Delta_{\text{perc}}^* \approx 0$$

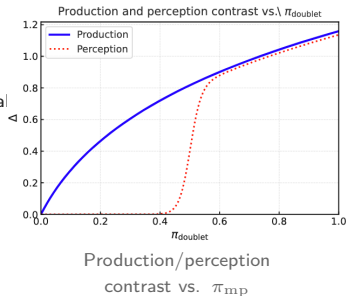
The production curve is analytically grounded; the perception curve emerges from the coupled production–perception loop.

Discussion

Discussion: what the model shows

What the model shows

- Production and perception need not share one exemplar store (Morley, 2023; Pinget, 2015).
 - They start aligned, but update in separate interacting stores.
 - Mismatch can emerge from the loop itself.
- Active minimal-pair support keeps near-merger alive.
 - More doublets \rightarrow more contrast-protection updates.
 - Under current settings, even one active T2–T5 minimal pair can sustain a production residue.
 - With no active minimal pairs, the system collapses to full merger.
- Perception is more fragile than production.
 - Ambiguous perceptual evidence can pool across T2 and T5.
 - Production tokens are written back to the intended lexical item.
- Near-merger is the intermediate regime.
 - $\Delta_{\text{prod}}^* > 0$, while Δ_{perc}^* is weak or near zero.



Even sparse lexical support can keep production contrast alive in the model, while perception may still weaken.

Near-merger need not be a transitional phase of sound change; it can be stable.

In this model, a near-merger-like regime can arise from the interaction of:

- production bias (reduction pressure)
- local minimal-pair support
- asymmetric production–perception updating

Functional load helps condition which long-run state the system approaches: merger, near-merger, or contrast preservation.

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Thank you

Questions and comments welcome

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