The emergence of auditory contrast

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An application of the theory of auditory dispersion developed in Boersma & Hamann (2007: “The evolution of auditory contrast”) to the two-dimensional case of vowels
(Flemming 1995)
Phonology and phonetics separate but connected

The task of the listener:
comprehension

The task of the speaker:
production

underlying form

/surface form/

[auditory form]

[articulatory form]

‘meaning’
Required assumptions

• Bidirectional use of constraints and their rankings
  (Smolensky 1996; Tesar & Smolensky 2000;
Pater 2004; Apoussidou & Boersma 2004)
• Learners first optimize comprehension, then just produce
  (Boersma 2006 “prototypes”; Boersma & Hamann 2007)
• Lexicon-driven learning of perception
  (Boersma 1997; Escudero & Boersma 2001; F. Eisner 2006)
• Stochastic OT + Gradual Learning Algorithm
  (Boersma 1997; Boersma & B. Hayes 2001)
• Parallel multi-level evaluation
  (Boersma 2005 “h-aspiré”; Apoussidou 2006)
• Phonological elements emerge during acquisition
  and have arbitrary relations to the phonetics
  (Boersma 1998; Blevins 2004; Mielke 2004;
   Boersma, Escudero & R. Hayes 2003; Morén today)
Perception maps AudF to SF

The task of the listener: comprehension

The task of the speaker: production

Underlying form

Surface form

Articulatory form

Auditory form

‘meaning’
Cue constraints

(assumption of arbitrary phonetic-phonology relations:)

• Any phonology element (e.g. /a/, /i/) can be connected to any auditory value (backness 0 to 100, height 0 to 100):

\[
\begin{align*}
/a/[bk0] & \quad /i/[bk0] & \quad /a/[hi0] & \quad /i/[hi0] \\
/a/[bk1] & \quad /i/[bk1] & \quad /a/[hi1] & \quad /i/[hi1] \\
\vdots & \quad \vdots & \quad \vdots & \quad \vdots \\
/a/[bk99] & \quad /i/[bk99] & \quad /a/[hi99] & \quad /i/[hi99] \\
/a/[bk100] & \quad /i/[bk100] & \quad /a/[hi100] & \quad /i/[hi100]
\end{align*}
\]

• The typology has to follow from acquisition and evolution, not from factorial permutation of constraints.

• In acquisition, all cue constraints start at the same height.
### Adult perception tableau

(from Boersma & Escudero 2004)

<table>
<thead>
<tr>
<th></th>
<th>*/a/</th>
<th>*/u/</th>
<th>*/o/</th>
<th>*/e/</th>
<th>*/i/</th>
<th>*/e/</th>
<th>*/i/</th>
</tr>
</thead>
<tbody>
<tr>
<td>[bk15, hi80]</td>
<td>[hi80]</td>
<td>[bk15]</td>
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<td>[bk15]</td>
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</tbody>
</table>
Child’s lexicon-driven perceptual learning

Lexicon tells the child: “you should have perceived /i/”

<table>
<thead>
<tr>
<th></th>
<th>*/a/</th>
<th>*/u/</th>
<th>*/o/</th>
<th>*/i/</th>
<th>*/e/</th>
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<tr>
<td>[bk15, hi80]</td>
<td>[hi80]</td>
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<td>[hi80]</td>
<td>[bk15]</td>
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<tr>
<td>/a/</td>
<td>*!</td>
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<td>/e/</td>
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<td>←*</td>
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<td></td>
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<td>/i/</td>
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<td></td>
<td>*!→</td>
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<tr>
<td>/o/</td>
<td></td>
<td>*!</td>
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<tr>
<td>/u/</td>
<td>*!</td>
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</table>
Environment for Generation-1 learners
Acquiring optimal perception

• Initial state of acquisition: all cue constraints ranked at 100.0, correct lexicon in place (I admit: a slightly unnatural situation).

• Then: lexicon-driven learning of perception by OT + GLA.

• The cue constraints end up being ranked in such a way that every possible auditory event (backness-height combination) is most often classified (by the listener) as the phonological category (/1/, /2/, /3/, /4/, /5/) that was most likely intended by the speaker.

• Thus, the listener becomes a maximum-likelihood listener, or more precisely, a probability-matching listener (Boersma 1997, Escudero & Boersma 2001).

• This is good, because this minimizes confusion.
‘Production’ (version 1) maps SF to AudF

The task of the listener: comprehension

The task of the speaker: production

meaning

|underlying form|

/surface form/

[auditory form]

[articulatory form]
‘Production’ with cue constraints only

(assumption of bidirectional use of constraints and rankings)
(assumption of first optimize perception, then just produce)

The average incoming /2/ is [bk20, hi80], but:

<table>
<thead>
<tr>
<th>/2/</th>
<th>*/2/</th>
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<tbody>
<tr>
<td></td>
<td>[hi0]</td>
<td>[hi20]</td>
<td>[bk80]</td>
<td>[bk20]</td>
<td>[hi80]</td>
<td>[bk9]</td>
<td>[hi65]</td>
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<td>*</td>
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<td>[bk9, hi80]</td>
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<td></td>
<td>*!</td>
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The ‘prototype’ effect

(observed in the lab by e.g. Johnson, Flemming & Wright 1993; modelled in OT for the 1-dimensional case by Boersma 2006)
Real production maps SF to AudF + ArtF

(assumption of parallel multi-level evaluation)

The task of the listener:
comprehension

The task of the speaker:
production

'meaning'

| underlying form |

/surface form/

[auditory form]

[articulatory form]
Rankings of articulatory constraints
Production with cue constraints and articulatory constraints

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- The articulatory effect counteracts the prototype effect a bit (modelled for the 1-dimensional case by Boersma 2006).
Production of Generation-1 learners

![Diagram showing the production of Generation-1 learners with auditory backness and auditory height axes.]
Evolution: production of Generation-2 learners

(for the 1-dimensional case see Boersma & Hamann 2007)
Production of Generation-3 learners

![Diagram showing auditory backness and auditory height for Generation-3 learners. The diagram is color-coded with areas labeled 1, 2, 3, 4, and 5, indicating different regions of production.]
Production of Generation-5 learners

![Diagram showing production of Generation-5 learners with auditory backness and auditory height axes. The diagram includes labeled regions: 1, 2, 3, 4, and 5.]
Comparison of inventory models

• Markedness accounts: do not go through for [i].
• Computing optimal inventories (Lindblom; Ten Bosch 1991): teleological; no connection to phonological phenomena.
• MINDIST constraints (Flemming; Padgett 2003; Sanders 2003): teleological.
• Clustering (De Boer 1999; Oudeyer 2006): non-teleological; but no repulsion, hence no chain shifts.
• Use the prototype effect of exemplar theory (Blevins 2004:285): non-teleological, but not yet shown to work; little connection to phonology yet; possibly problematic in more dimensions.
• Multi-level bidirectional OT (Boersma & Hamann 2007): non-teleological; connected to phonology via SF and OT; shown to work; scales linearly with number of dimensions.
Conclusion

Auditory dispersion is taken care of in the phonology-phonetics interface, in a way compatible with phonological theory.

Auditory dispersion is seen to emerge non-teleologically, if we assume *multi-level bidirectionality*.

For a technically detailed account of the one-dimensional case, look next week on Rutgers Optimality Archive for:

“The evolution of auditory contrast”
by Paul Boersma & Silke Hamann