Theories of Vowel Systems:
Quantal Theory and Adaptive Dispersion

1. There are a huge (even infinite) number of different articulations that can be made. Obviously, they are not all used in any language. But even across languages, certain speech sounds are very common, while others are quite rare.
• Both Quantal Theory and the Theory of Adaptive Dispersion seek to explain why certain sounds—and certain systems of sounds—are favored cross-linguistically.

Quantal Theory
(Stevens 1972, 1989)

2. The acoustic theory of speech production explains the relation between vocal tract configurations and acoustic output. In general, when you change the configuration of the vocal tract, you change the acoustic output. However, the relation between articulatory parameters and acoustic output is not linear.

- There is a large acoustic (and auditory) difference between regions I and III.
- Within regions I and III, however, the acoustic parameter is relatively insensitive to change in the articulatory parameter. In other words, changes in articulation don’t have much effect on the speech output.

3. Stevens’ claim is that linguistic contrasts involve differences between ‘quantal’ regions (I and III).
   • All quantal regions define contrastive sounds and all contrastive sounds differ quantally.
   • Or at least, quantal distinctions are preferred.

4. Why do quantal regions influence sound systems?
   • Articulations don’t have to be precise to produce a certain output.
   • And continuous movement through the region will yield an acoustic steady state.
   • Articulatory sloppiness won’t affect perceptibility.
• Furthermore, articulatory space is necessarily continuous, but different articulations can produce qualitatively different acoustic effects.
• The plateau-like regions are the correlates of distinctive features.

5. Examples of quantal categories over an articulatory continuum:
• Degree of glottal constriction: complete opening for voiceless sounds to less opening for modal voicing to complete closure for a glottal stop
• Degree of vocal tract constriction: vowel (low V – mid V – high V) to glides to fricatives to stops
• Place of articulation for vowels (i.e., place of constriction)

6. Quantal theory applied to vowels:
Recall that nomograms show us the acoustic consequences (in terms of formant frequencies) of varying a single articulatory parameter (place of constriction).
• There are regions of acoustic stability (quantal regions) where two formants converge.

• [a] is produced at the convergence of F1 and F2, where the front and back cavities of the vocal tract are of approximately equal lengths.
• [i] is produced at the convergence of F2 and F3, created by a constriction in the palatal region. (Remember, F1 results from the Helmholz resonator.)
• [u] is produced at a broad F2 minimum, where F2 is near a stable F1.

These three vowels are ‘quantal vowels’. Thus, they should be highly preferred cross-linguistically, and in fact they are.

7. The upshot of Quantal Theory is this: Speakers can get away with articulatory sloppiness if languages make use of quantal phonetic categories. Near-continuous articulations yield discrete acoustic (perceptual) categories.

Segments that exploit quantal regions (regions of stability) will be common across languages. (Segments that depend on distinctions within a quantal region will be rare.)

• However, there are significant criticisms of Quantal Theory. It predicts greater similarity in acoustic detail across languages than is observed. It doesn’t predict the range of contrasts that are attested cross-linguistically. It doesn’t account for distinctions that rely on multiple articulatory parameters (a region of stability for one may be unstable for another).
• It’s not actually clear that allowing for articulatory sloppiness is so necessary. A postulated advantage of sounds whose acoustics are relatively insensitive to articulatory variation is that this allows imprecision in articulation without disastrous acoustic consequences. But languages do not seem to take consistent advantage of this.

Theory of Adaptive Dispersion

8. The theory of Adaptive Dispersion offers an alternative explanation for the cross-linguistic preference for the vowels [i, a, u]. These vowels are not only in potentially stable articulatory regions, but they are at the extremes of the physiologically possible vowel space. So they are maximally acoustically distinct and are unlikely to be confused by a listener.

• Assumption: Listeners’ abilities to hear vowel distinctions provide a selectional pressure on segment inventories (diachronically).

• The perspective is shifted from exploring preferred/dispreferred sounds to preferred/dispreferred systems of contrasts.

e.g., certain vowel inventories are common:

<table>
<thead>
<tr>
<th>i</th>
<th>u</th>
<th>i</th>
<th>u</th>
<th>i</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>e</td>
<td>o</td>
<td>e</td>
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</tbody>
</table>

others are unattested:

<table>
<thead>
<tr>
<th>i</th>
<th>u</th>
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<tbody>
<tr>
<td>e</td>
<td>a</td>
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(continued from Flemming notes)
9. The Theory of Adaptive Dispersion posits that the sounds in a given language are ‘selected’ to best satisfy a functional requirement of maximal (or, in later versions, sufficient) perceptual distinctiveness.
   - In particular, Adaptive Dispersion describes how the requirement of perceptual contrast predicts vowel inventories.

10. In order to be testable, the Theory of Adaptive Dispersion has to quantify the notion of contrast.

    A **vowel space** is the acoustic/auditory range of vowels that are articulatorily possible. L&L look at a Mel-scaled F1 by F2 vowel space.

    \[ \rightarrow \] The mel scale is a transformation of Hz frequency based on auditory perception. So this vowel space is close to an auditory space. Perceptual contrast between two vowels is measured as the linear distance between them in mel. To maximize distinctiveness, the repulsion between them in minimized. For the vowel system as a whole, the repulsion for all the pairs of vowels is simultaneously minimized.

11. Optimal vowel inventories of various sizes are predicted:

    (from Liljencrants & Lindblom, 1972)
12. Essentially correct patterns are predicted for 3 to 6 vowel systems. For larger systems (7 +), various errors occur (including the prediction of too many high central vowels), though generally not more than one per system, according to L&L. Perceptual distinctiveness (contrast) plays an important, but not exclusive, role as a determinant of the structure of vowel systems.

- However, there are weaknesses of Adaptive Dispersion Theory aside from certain specific incorrect predictions. It doesn’t address the issue of why languages have inventories of various size inventories, or why they would have large inventories. It doesn’t explain why there is cross-language variation in the distribution of the same number of vowels (meaning some languages must have sub-optimal inventories). And it doesn’t consider any issues related to articulation (ease of articulation, etc).

13. Lindblom also discusses the relevance of phonetics to the study of language, with respect to a theory like his (and, although he doesn’t say so, like Quantal Theory as well). Before L&L and Stevens, phonetics had mainly played the role of ‘interpreting’ linguistic form into a realizable physical output. It’s focus was speech, rather than language.

- But Adaptive Dispersion Theory (like QT) seeks to derive linguistic form as a consequence of the various mechanisms of speech communication.
- Quantitative models show how these mechanisms affect higher-level linguistic and communicative structure.