## **Main Points**

- 1. Present a general multidimensional search algorithm
- 2. Test algorithm for biases
- 3. Test algorithm with human listeners

# Background

# Why are multidimensional search methods needed?

- Evidence from both production and perception of labial stops suggest that multiple acoustic cues may be important for categorization.
- Caramazza, Yeni-Komshian, Zurif, & Carbone, 1973
- Lisker & Abramson, 1964
- Traditional low-dimensional methods are inadequate for exploring highdimensional spaces.
  - Forced identification
  - 2-D Method of Adjustment (MOA) (Johnson, Flemming & Wright, 1993)

# Iverson & Evans (2003)

- Proposed method for finding best exemplars in a five-dimensional acoustic vowel space.
- Used goodness judgments direct movement through the stimulus space.
- "best exemplars can be found within the set of 100,700 possible vowels after playing subjects only 35 trials per vowel category"
- Rapid convergence achieved by using special relationships between dimensions.
- Not generalizable

# Research Quetions

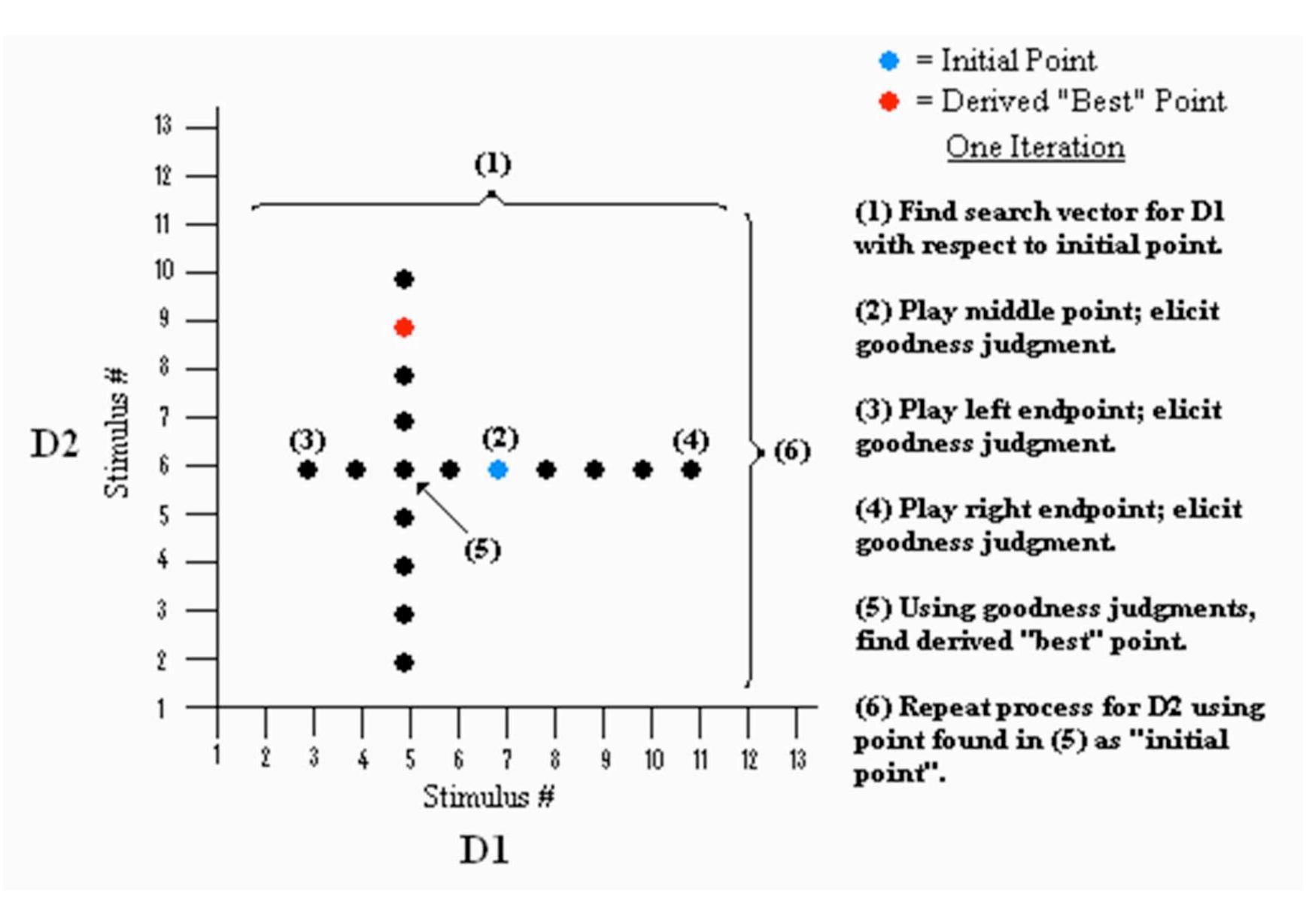
- 1. How can the Iverson and Evans (2003) search algorithm be made more general?
- 2. Does the proposed Algorithm for Multidimensional Best Exemplar Locations (AMBEL) have any inherent biases?
- 3. What types of data are generated by the AMBEL?
- 4. Does the AMBEL work?
- 5. What are uses/limitations of the AMBEL?

# 4aSC9. Finding perceptual categories in multidimensional acoustic spaces.

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## AMBEL

- AMBEL operates using six basic principles (see Fig. 1 for sample operation):
  - 1. Search vectors restricted to one dimension.
  - 2. Goodness judgments from 3 points on a search vector steer the search
- 3. Slider bar used to get goodness judgments not reset between stimulus presentations.
- 4. Only 67% of a dimension is searched at a time.
- 5. All dimensions are probed before a dimension is probed again.
- 6. Multiple iterations of the search process are used to achieve convergence.

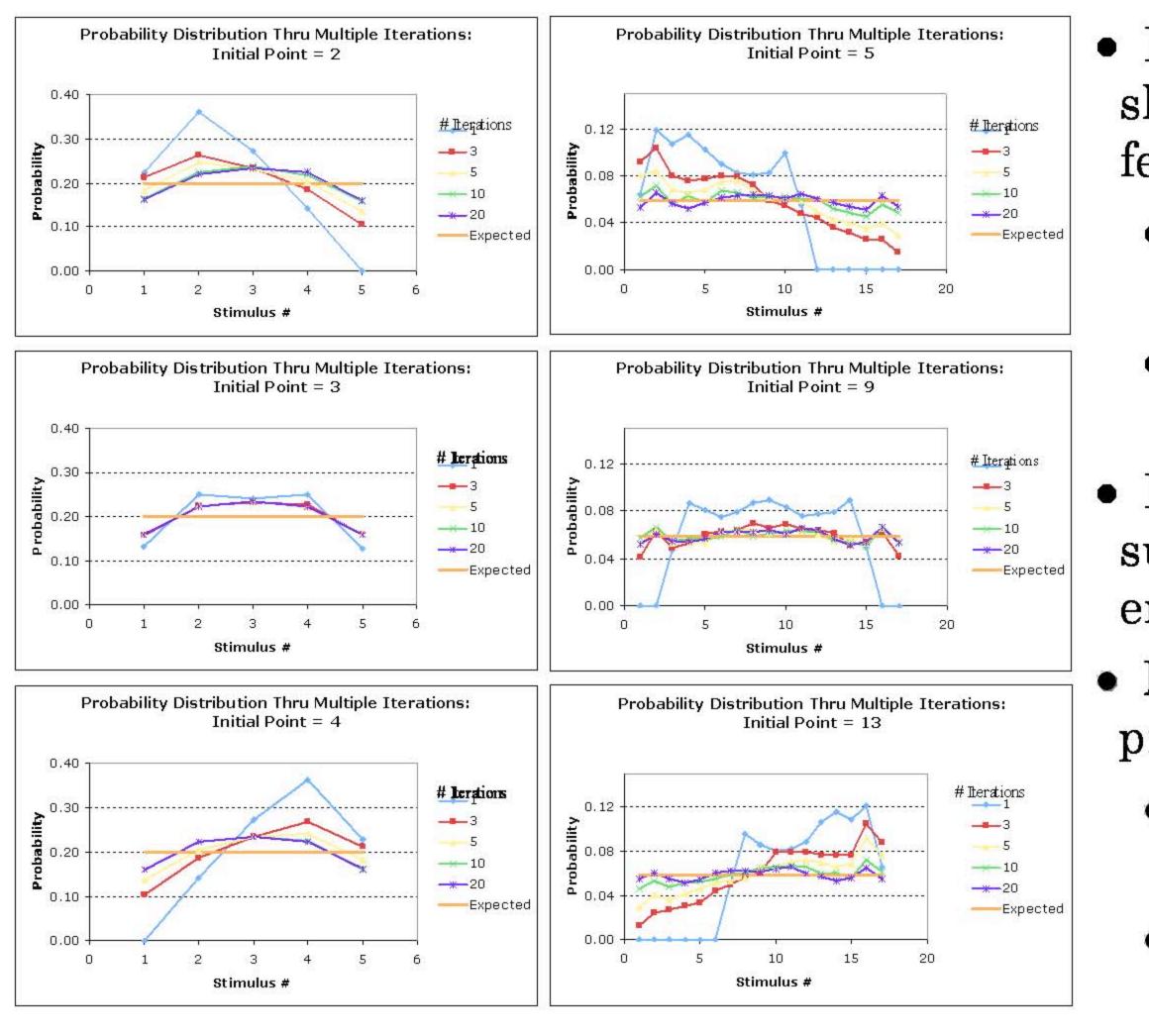


**Figure 1: Example of search procedure.** Schematic of what the search routine would look like if implemented in a 2-dimensional space. The filled circle would be the initial point if D1 were searched again.

# Test for Biases: Computer Simulations

- Examined algorithm destination point probabilities.
- Random goodness judgments fed into algorithm.
- Three factors examined:
- (1) Dimension size (# stimulus variable steps)
- (2) Initial starting point (which point algorithm started from)
- (3) Number of iterations (# times thru search process)
- Dimensional independence meant that single dimension search sufficient for testing.

#### $DIM SIZE = 5 \qquad DIM SIZE = 17$



- Effect of dimension size shows up in boundary effects.
- Endpoints have slightly depressed probabilities
  Most noticeable when di-
- mension size is small.
  Effect of initial point is substantial if number of it-
- erations is small.
  More iterations flatten probability function.
- Small ripple always present.
- Flattening is quicker with middle initial point.

# Test with Human Listeners: /p/ vs. /b/

# <u>Methods</u>

#### A. Stimuli

- 5-dimensional acoustic space created by varying properties known to affect the voicing categorization of initial stops (see handout for more info.):
- **F0** (5 levels)

Figure 2: Search destination points using random goodness judgments

- Amount of formant transition (4 levels)
- Vowel onset amplitude ramping (11 levels)
- **VOT** (17 levels)
- Burst release amplitude (14 levels)
- Size of space: 5\*4\*11\*17\*14 = 52,360 stimuli

# Test with Human Listeners: /p/ vs. /b/ (cont.)

# Methods (cont.)

#### B. Search Algorithm

- The same general algorithm described earlier
- 3 iterations; 4 initial points
- Following data collection, implementation error discovered
- "Leftward" bias in the space
- Effect of bias shown in red in figures below

#### C. Interface

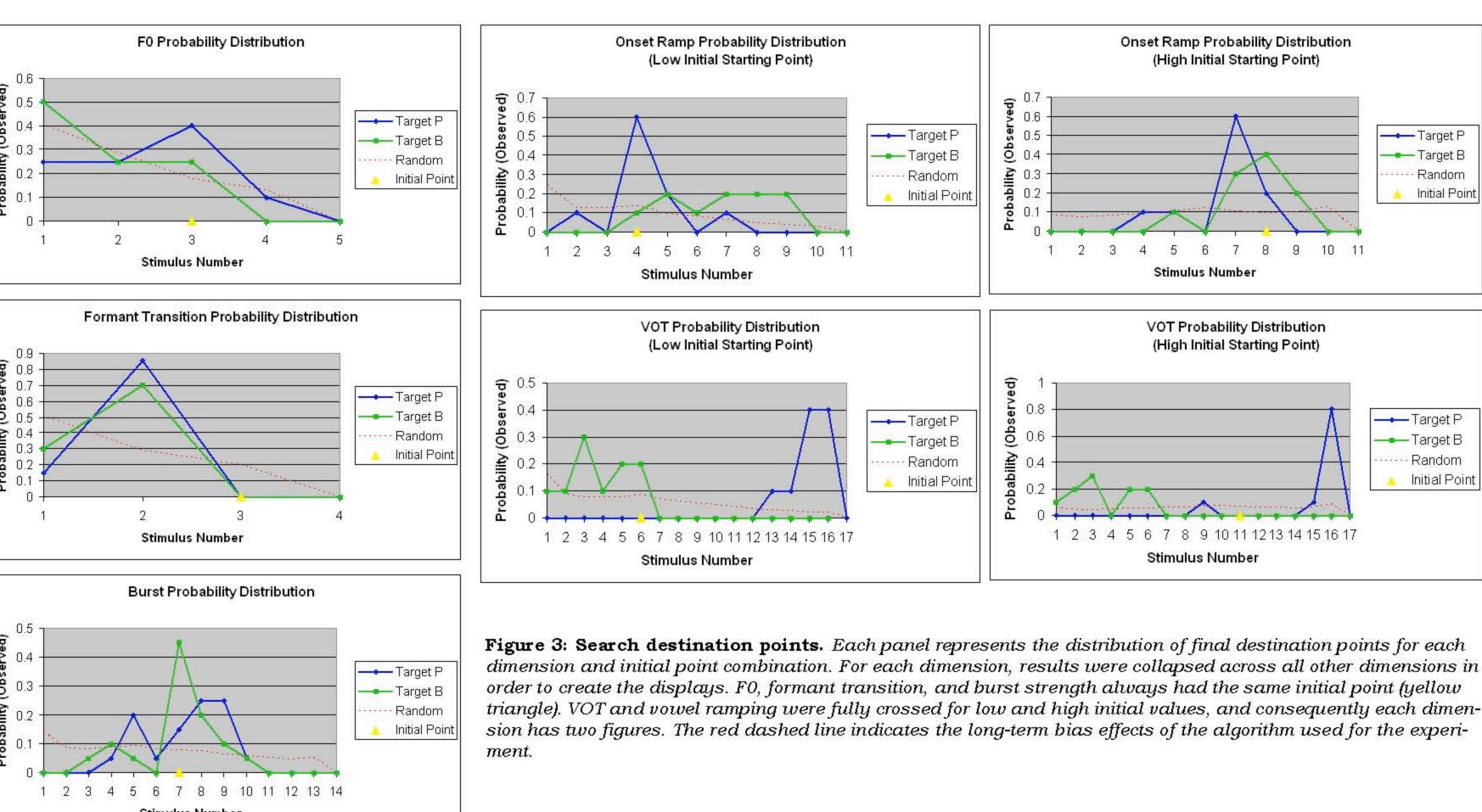
- A GUI containing the following:
- Slider bar for eliciting goodness judgments
- Text prompt for target phoneme

#### D. Listeners

• Five native speakers of English participated in the experiment.

#### Results

#### A. Destination Points



#### B. Search Vector Response Tendencies

- Design of the algorithm allowed for direct comparison of goodness judgments elicited from search vector endpoints.
- These response tendencies indicate dimensions important for categorization.

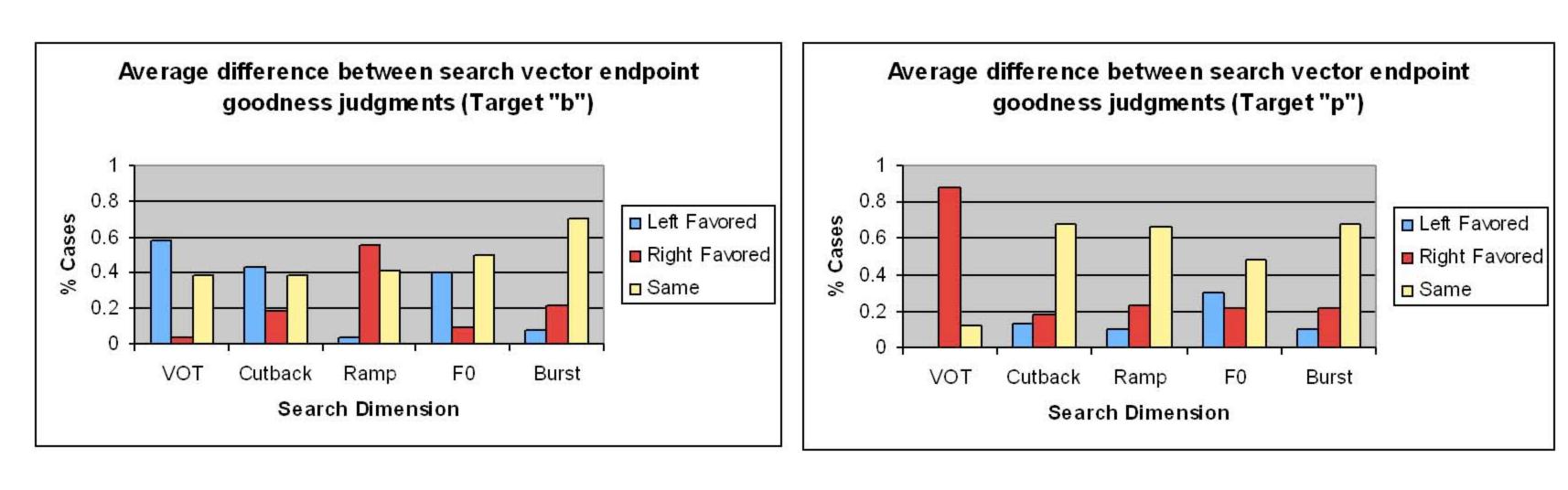


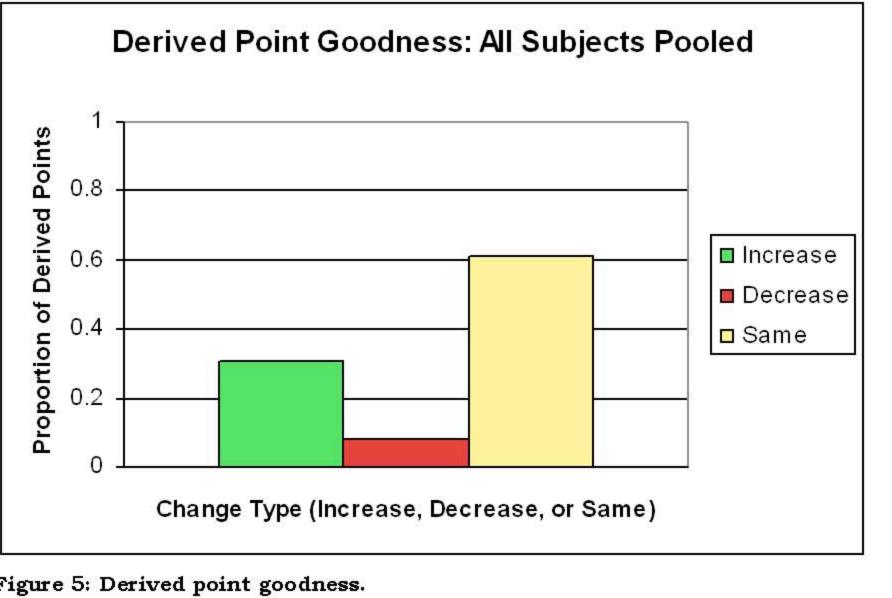
Figure 4: Search vector endpoint response tendencies. For both target /b/ (left panel) and target /p/ (right panel) the proportion of cases where either the left or right endpoint had the higher goodness judgment is indicated for each search dimension. Results are averaged across responses from all five listeners.

# Test with Human Listeners: /p/ vs. /b/ (cont.)

## Results (cont.)

# C. Algorithm tracking performance

• The success of the algorithm in steering listeners into regions of better exemplars can be estimated by comparing the goodness ratings from the right endpoint of the search vector and the middle point of the next dimension's search vector (see Fig. 1).



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- If the algorithm is functioning properly, the goodness rating of the derived stimulus should be greater than the one that preceded it.
- Overall, the algorithm appeared to be work properly (see Fig. 5).

# Discussion

#### A. Generality

- The primary constraint on the search method is that it must be possible to elicit gradient goodness judgments from the stimuli.
- In principle, multi-modal searches are possible (i.e. visual, acoustic, tactile, etc...).

#### **B.** Limitations

• This method will not produce high-resolution pictures of phonetic categorization; rather, the primary function of the algorithm is to provide a first approximation of the important factors involved in stimulus categorization.

### Conclusions

- 1. AMBEL is in principle general enough to be applied to any stimulus space (i.e. dimensions need not be solely acoustic) in which gradient goodness ratings are possible.
- 2. Minimal inherent biases were found.
- 3. AMBEL generates multiple data types that can be used to refine lower dimensional searches as well as evaluate the tracking effectiveness of the algorithm.
- 4. AMBEL appeared to successfully identify important acoustic dimensions for the categorization of /p/ and /b/ by native speakers of English.
- 5. AMBEL should not be seen as a "magic bullet" for finding category centers; rather, it is a first approximation tool that should be augmented by more sensitive low-dimensional search methods.

### References

Caramazza, A., G.H. Yeni-Komshian, E.B. Zurif, & E. Carbone (1973). The acquisition of a new phonological contrast: the case of stop consonants in French-English bilinguals. J. Acoust. Soc. Am., 45, 4231-4328.

Iverson, P. & Evans, B. G. (2003). A goodness optimization method for investigating phonetic categorization. Paper presented at the 15th International Conference of Phonetic Sciences.

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