Exemplar models and the perceptual magnet effect

Gerhard Jäger
Gerhard.Jaeger@uni-bielefeld.de

June 23, 2008

Bielefeld

Overview

- Kuhl's 1992 experiments
- additional findings: Kuhl et al. 1992
- Lacerda 1995
- echoes of exemplars
  - Hintzman's and Goldinger's model
  - implications for the perceptual magnet effect

Kuhl 1992

main findings

- vowel categories have prototypical elements
- prototype "warps the perceptual space":
  - equal psycho-physical distance are perceived as smaller in the neighborhood of prototypes
  - prototype acts like a "magnet" (or rather as a center of gravity in Einstein's general theory of relativity)
- effect is
  - strong for adults
  - weak but significant for infants
  - absent for monkeys

Experimental setup

- two reference stimuli were picked out (a prototypical and a non-prototypical /i/)
- test stimuli were arranged on 4 orbits of increasing size around the reference vowels
- test persons are English native speakers

Experimental setup

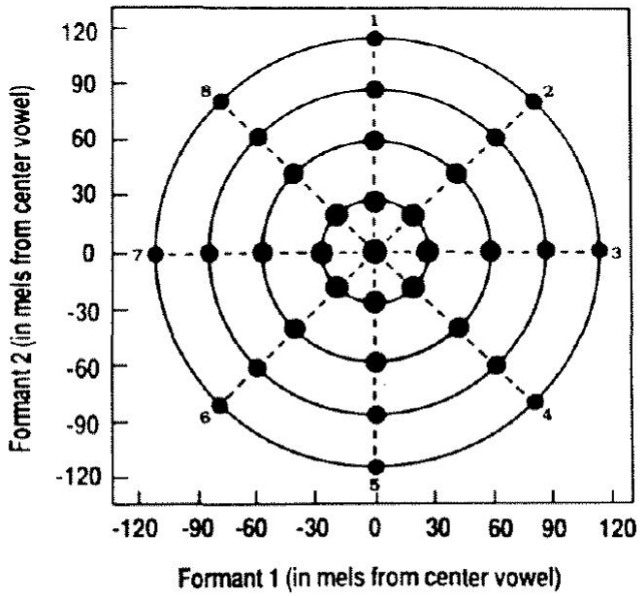


Figure 1. Formant frequency values in mels for stimuli surrounding a center vowel stimulus. The stimuli form four orbits and eight vectors around the center stimulus. The stimuli on each orbit are a specified distance in mels from the center vowel (30, 60, 90, or 120 mels, starting from the first orbit); the eight stimuli on each orbit differ in the direction and amount of formant frequency change.

Experimental setup

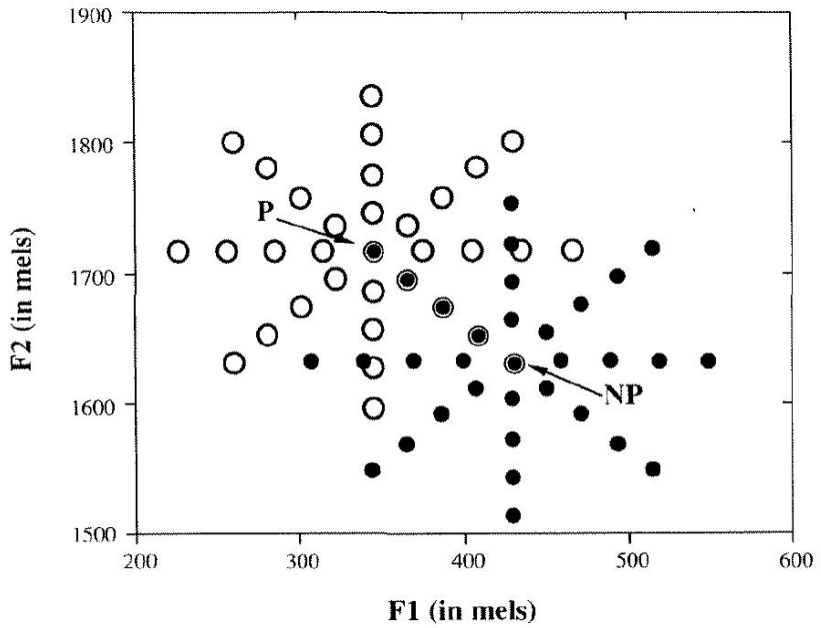


Figure 2. The prototype /i/ vowel (P) and variants on four orbits surrounding it (open circles) and the nonprototype /i/ vowel (NP) and variants on four orbits surrounding it (closed circles). The stimuli on one vector were common to both sets.

Experiment 1: category goodness

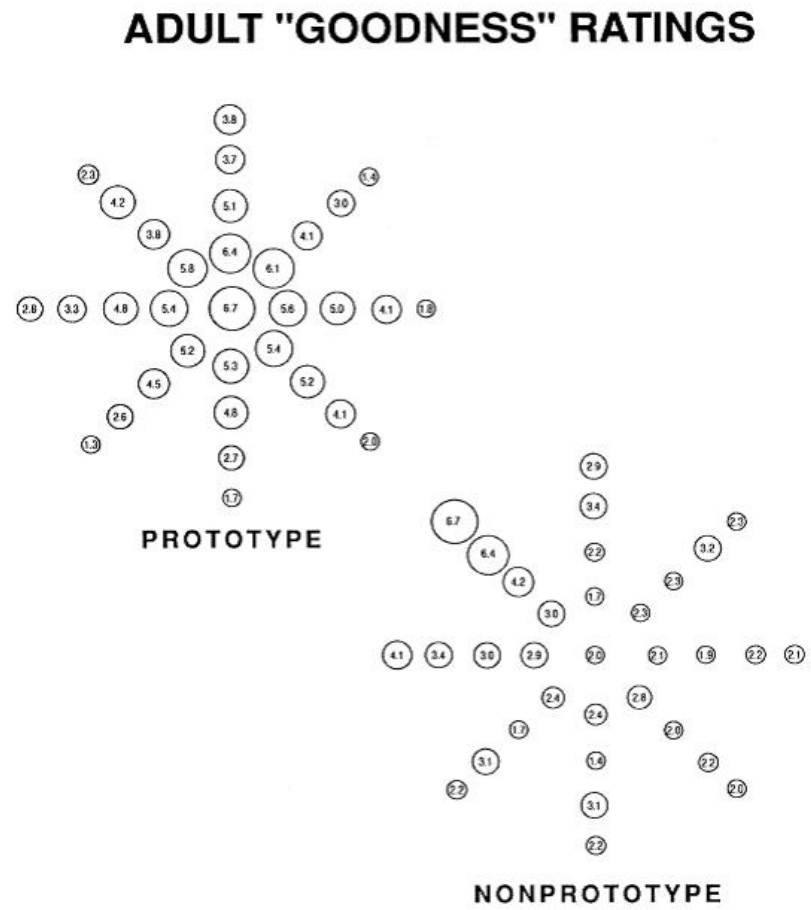


Figure 3. Category goodness (typicality) ratings for the prototype /i/ vowel, the nonprototype /i/ vowel, and the variants surrounding each of the two vowels. Typicality was judged by adults using a scale from 1 (a poor exemplar) to 7 (a good exemplar). The size of the circles correlates with the degree of goodness, with larger circles indicating better exemplars.

Experiment 2: magnet effect with adults

Experiment 2

- test persons were exposed to a *referent* speech sound (P or NP) and a *comparison* speech sound (one of the points on one of the orbits)
- test persons had to press a button when the comparison vowel was played
- in *test trials*:
  - referent vowel was changed to comparison vowel
  - correct responses were reinforced by visual signal
- in *control trials*:
  - only referent vowel was played
  - false-positives were monitored
- 128 trials (32 test stimuli $\times$ 2 trials each $\times$ 8 test persons)

Experiment 2: magnet effect with adults

- diagram: total correct responses (positive and negative):

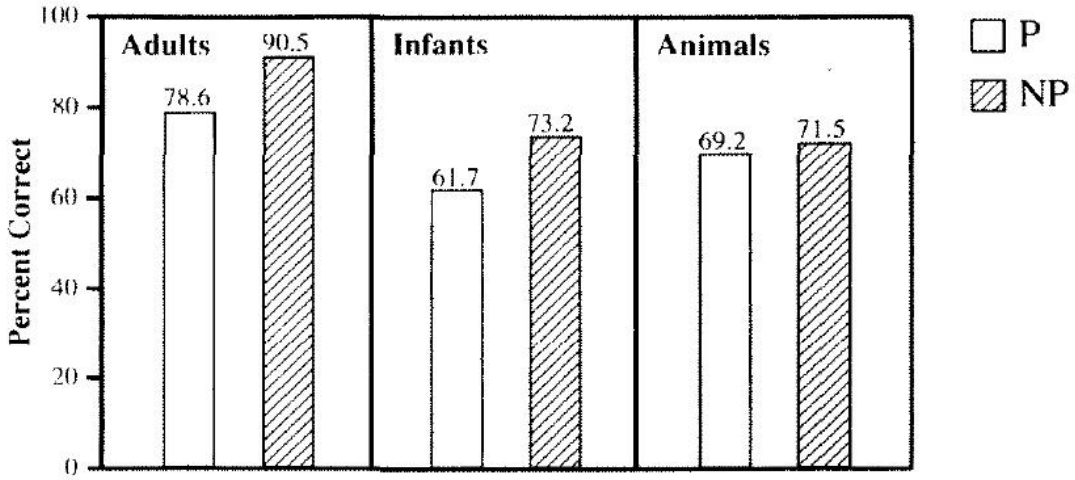
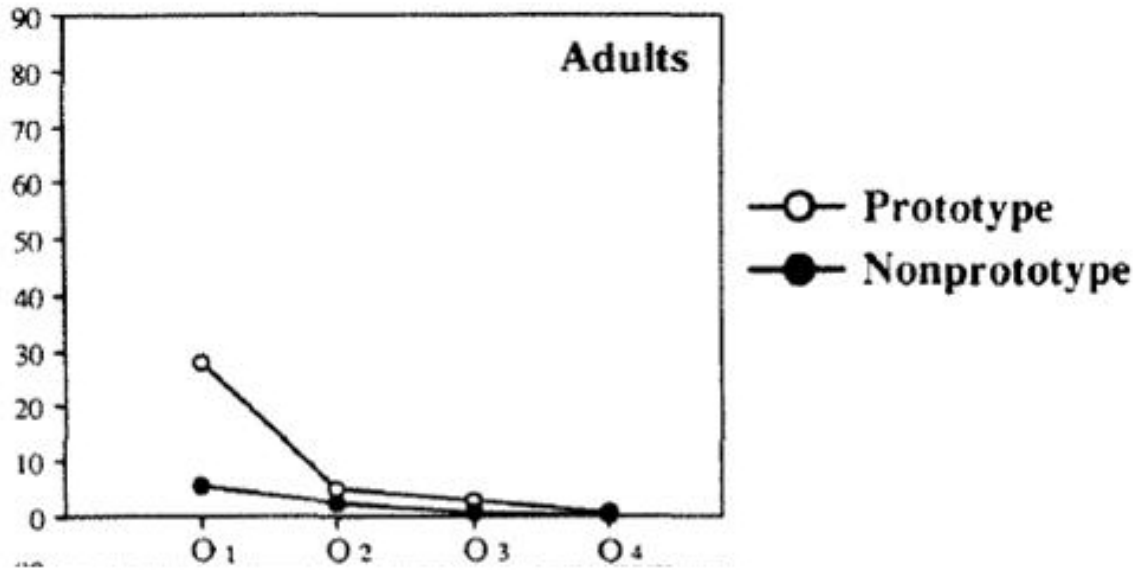


Figure 4. Average overall percent-correct scores achieved by adults (Experiment 2), infants (Experiment 3), and monkeys (Experiment 4) in the prototype (P) and the nonprototype (NP) conditions. For adults and infants (but not monkeys), there is a statistically significant difference between scores in the two conditions, with overall percent-correct scores being higher in the nonprototype condition.

Experiment 2: magnet effect with adults

- diagram: correct generalization as function of psychophysical distance



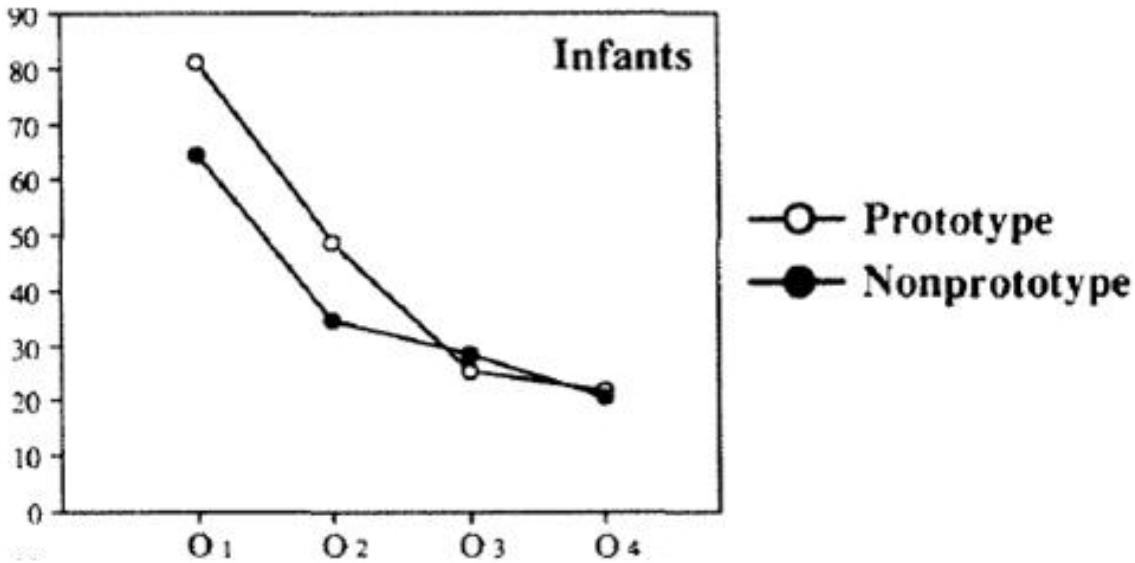
Experiment 3: magnet effect with infants

setup

- similar to previous experiment
- head-turn responses were counted
- correct positives were reinforced by a toy animal that started moving
- actual experiment was preceded by a training phase were test subject were conditioned to perform head-turns when vowel quality changes

Experiment 3: magnet effect with infants

- diagram: correct generalization as function of psychophysical distance



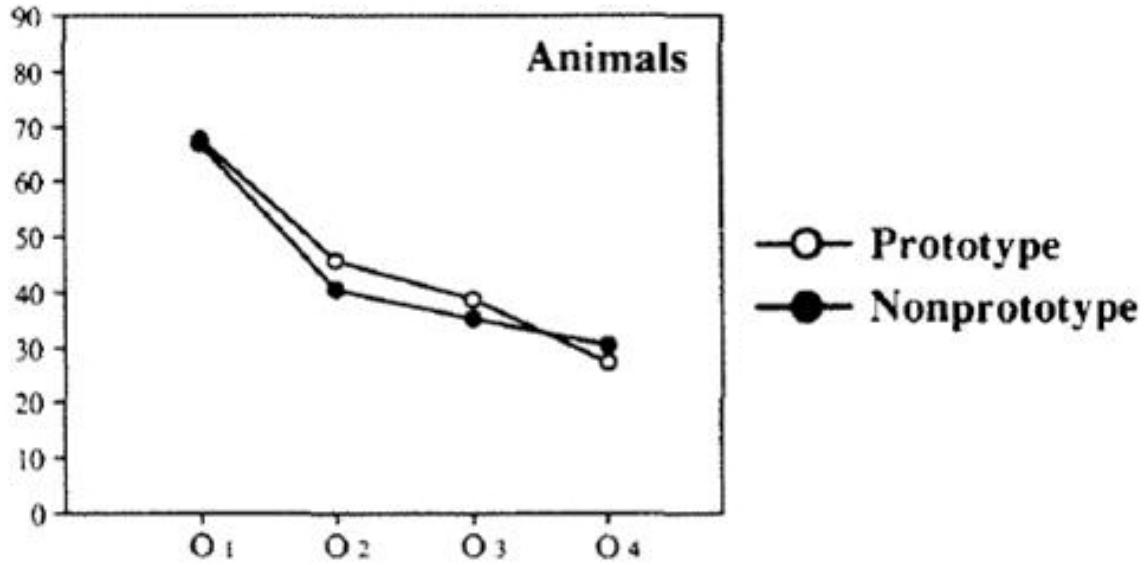
Experiment 4: magnet effect with monkeys

setup

- similar to previous experiment
- subjects were rhesus macaques
- key-release instead of head-turns
- correct positives were reinforced by food rather than a toy
- no significant difference between prototype and non-prototype condition

Experiment 4: magnet effect with monkeys

- diagram: correct generalization as function of psychophysical distance



Kuhl et al. 1992

- "Linguistic Experience Alters Phonetic Perception in Infants by 6 Months of Age" (Science, 1992)
- main finding:
  - perceptual magnet effect is confirmed
  - location of prototypes depends on native language
  - effect can be observed already with infants in pre-linguistic age
- comparison of American (native language: AE) and Swedish infants
- referent vowels: /i/ (is a phoneme in AE but not in Swedish) and /y/ (is a phoneme in Swedish but not in AE)

Experimental setup

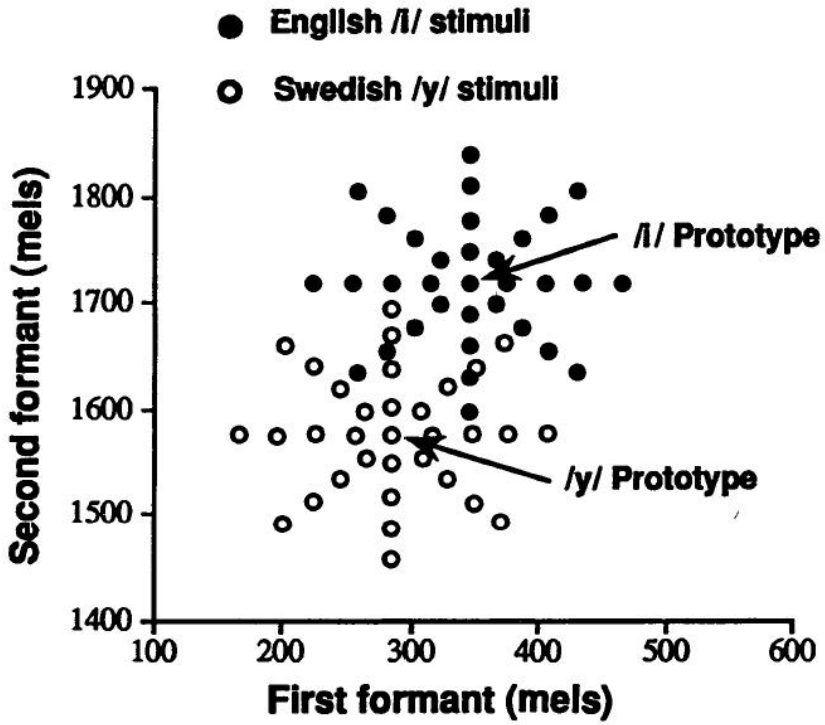
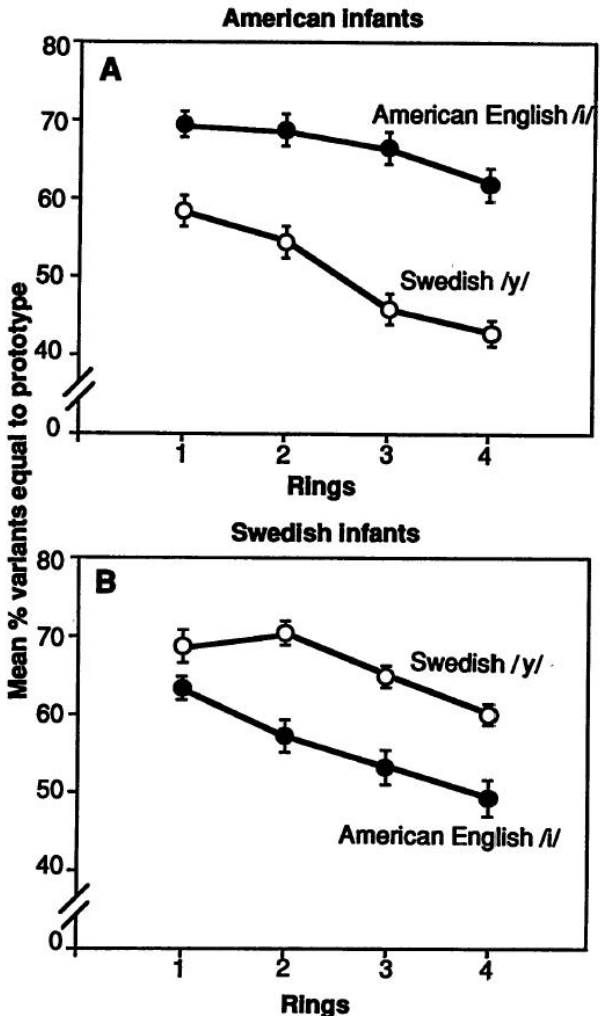


Fig. 1. Six-month-old infants from America and Sweden were tested with two sets of vowel stimuli, American English /i/ and Swedish /y/. Each set included an exceptionally good instance of the vowel (the prototype) and 32 variants that formed four rings (eight stimuli each) around the prototype (*8*).

Results

- both groups of infants showed perceptual magnet effect
- American infants treated /i/ and Swedish infants treated /y/ as prototyp



Exemplar theories

Lacerda 1995/1998

- PME can be derived from exemplar model
- "prototype" of a category C is just a region where exemplars of this category have a high relative density (as compared to other categories)
- "similarity" between exemplars is (implicitly) defined as similarity in category memberships

Lacerda's model

- exemplars of a category are normally distributed in a one-dimensional space (generalizes to higher dimensionality)
- relative frequency of items of a category which has its mean at μ:

$$\mathrm{Class}(x, \mu, \sigma) = \frac{1}{\sqrt{2 \cdot \pi \cdot \sigma}} \cdot e^{-\frac{(x-\mu)^2}{2 \cdot \sigma^2}}$$

- number of items of category A within an ϵ-neighborhood of x_0:

$$\mathrm{NeighbA}(x_0, \epsilon) = \mathrm{TotalA} \int_{x_0-\epsilon}^{x_0+\epsilon} \mathrm{Class}(x, 0, \sigma) dx$$

Lacerda's model

- similarity of an exemplar to a category A (if B is the only competing category):

$$s(A, x_0) = \frac{\mathrm{NeighbA}(x_0, \epsilon)}{\mathrm{NeighbA}(x_0, \epsilon) + \mathrm{NeighbB}(x_0, \epsilon)}$$

- note that $\mathrm{NeighbA}(x_0, \epsilon)$ depends on abundance of A-exemplars, as well as on x_0 and ϵ

Lacerda's model

- suppose exemplars are distributed as follows:

Category	μ	σ	Exemplars in category
A	0	3	1000
B	3	1	100

- discrimination function:

$$\mathrm{discr}(x_0) = \frac{\left|\frac{d}{dx_0}s(A, x0)\right| + \left|\frac{d}{dx_0}s(B, x0)\right|}{\mathrm{Const}}$$

Lacerda's model

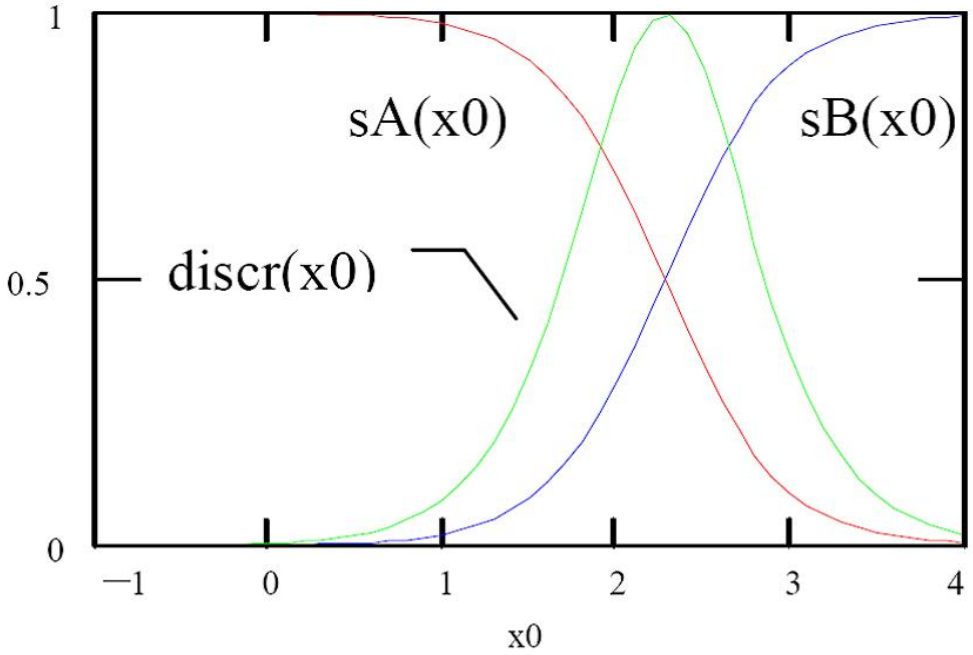


Figure 1. Similarity functions to classes A and B and discrimination function. Note that the category boundary is shifted towards category B because A contains a larger number of exemplars.

Derivation of the PME

- similarity between two exemplars x_1 and x_2 is (apparently) defined as

$$\begin{aligned} \mathrm{sim}(x_1, x_2) &= \int_{x_1}^{x_2} \mathrm{discr}(x)dx \\ &= \frac{1}{2}(|S(A, x_1) - S(B, x_1)| + |S(B, x_1) - S(B, x_2)|) \end{aligned}$$

Comparision with Kuhl's data

- goodness ratings from Kuhl 1991 were used to estimate exemplar densities
- from this average similarities to prototype were computed

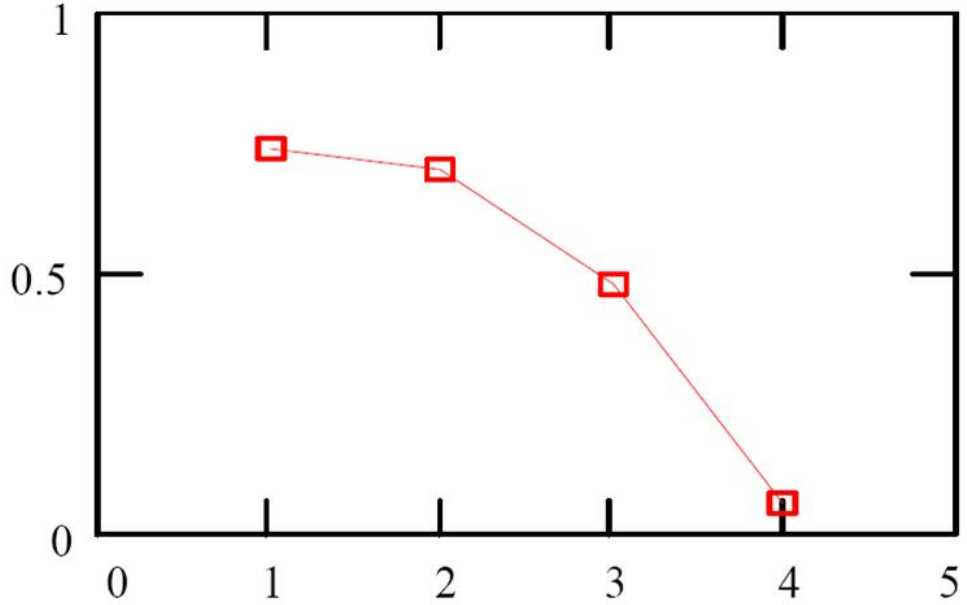


Figure 3. Computed generalization (arbitrary scale) as a function of the distance to the prototype.

Discussion

- NP condition is not computed, so strictly speaking the PME is not demonstrated
- however, discrimination function in figure 1 predicts similarity between equidistant points as a function of the distance from the prototype—magnet effect in the center of a category is predicted
- PME depends on **categorization**
- Kuhl's experiment with animals did not involve categorization, thus no PME

Critical points

- Kuhl et al. 1992 (with Lacerda herself being a co-author) demonstrates that PME occurs at an age where infants do not yet use vowels contrastively
- unclear whether 6 months infants already have categories
- similarity metric appears *ad hoc*

Echoes and the PME

Echoes of perception

- Hintzman (1986), Goldinger (1998):
  - observation causes stored exemplars to resonate
  - "echoes" are formed by superimposing resonating exemplars
  - what is stored in memory is not the observation itself (or a cognitive representation of it) but its echo
- model suggests an alternative exemplar-based explanation of the PME:
  - prototypes are just areas of high exemplar density (as in Lacerda's model)
  - each exemplar acts as a little magnet, pulling the echo of an observation towards itself
  - high density regions exert stronger attracting force, thus reducing distance between echoes as compared to distance between observations

Echoes and the PME

Details of the model

- exemplars are represented as n-dimensional vectors (unlike in Goldinger's model, n may be low, and the exemplar space is continuous rather than discrete)
- similarity between exemplars is a monotonically decreasing function of Euclidean distance:

$$\mathrm{sim}(x_1, x_2) = e^{\frac{\|x_1 - x_2\|^2}{\sigma^2}}$$

Echoes and the PME

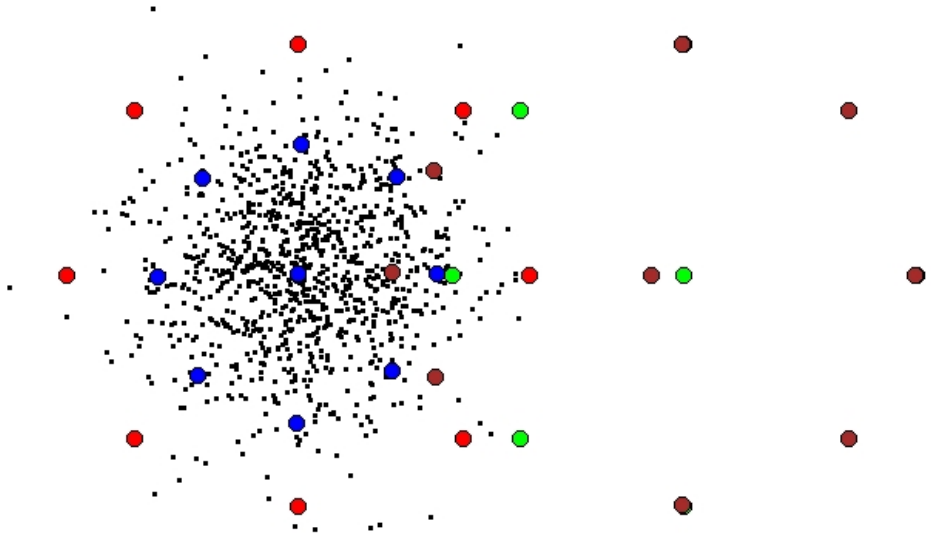
Details of the model

- Let o be an observation and ltm be the long term memory, i.e. a set of exemplars

$$\text{echo}(ltm, o) = \frac{o + \sum_{x \in ltm} \text{sim}(x, o)x}{1 + \sum_{x \in ltm} \text{sim}(x, o)}$$

- note that o itself is a component of its echo (otherwise the memory could not be initialized)

Echoes and the PME



- black dots: exemplars in long term memory
- red/green circles: observations
- blue/brown circles: their echos

Echoes and the PME

reconstruction of Kuhl's finding

- ltm initialized with 1000 exemplars, that were pseudo-randomly normally distributed around $(.5, .5)$ with $\sigma = .05$
- prototype: $(.5, .5)$, nonprototype: $(.75, .5)$
- orbits have a diameter of $.1$, $.2$, $.3$ and $.4$ respectively
- measured was average similarity of the elements of an orbit from the referent point
- qualitatively similar results are obtained for different parameter settings

Echoes and the PME