Computational Cognitive Science

Lecture 11: Concepts and Language

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Concepts in Language

Number concepts:

"x is odd"

"x is a power of 3"

"x is between 30 and 45"

[Tenenbaum, 2000]

Concepts in Language

Number concepts:

"x is odd"	$\{x = 2k + 1 : k \in N\}$
"x is a power of 3"	$\{x = 3^k : k \in N\}$
"x is between 30 and 45"	$\{30 \leq x \leq 45\}$

[Tenenbaum, 2000]

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[Tenenbaum, 2000]

- Not all concepts are equally "natural" in English.
- There are cross-linguistic differences between conceptual categories.

Concepts in Language

- New words in a given language:
  - "*selfie*" did not exist 20 years ago.
  - "*pink*" was (probably) not used as a color term until the color became popular in 18th century.

- "Untranslatable" words:
  - Dutch *gezelligheid* ("cozy and warm atmosphere")
  - Russian *toska* ("deep spiritual anguish without any specific cause")
  - English *privacy* (cannot be easily translated into Russian)

Concepts in Language

Even similar concepts are not necessarily “the same” across languages.

glass

cup

Concepts in Language

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EN	*glass*	*cup*
RU	*stakan*	*chashka*

Concepts in Language

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EN	*glass*	*(plastic) cup*	*(plastic) cup*	*cup*
RU	*stakan*			*chashka*

Concepts in Language

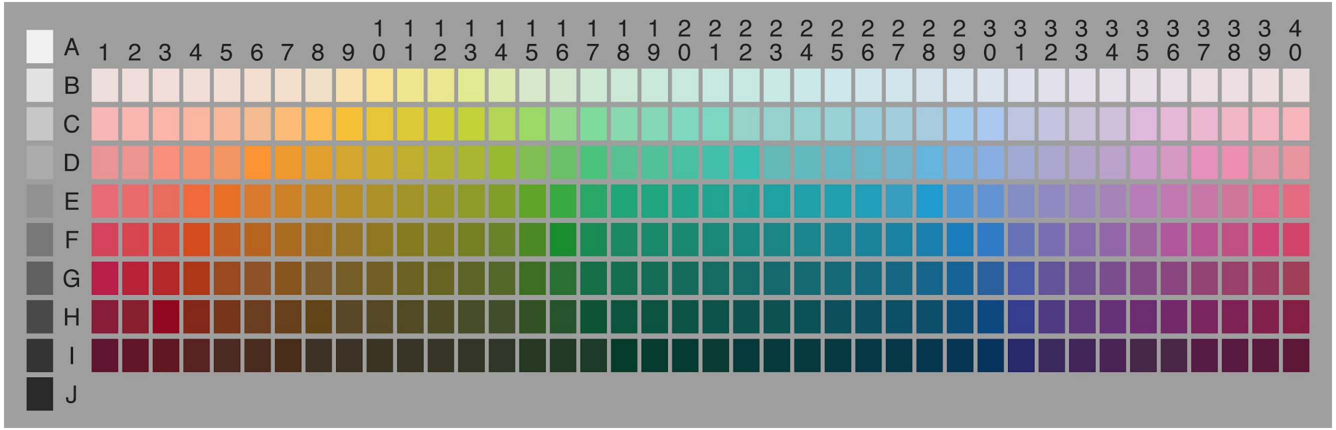
Even similar concepts are not necessarily “the same” across languages.

EN	*glass*	*(plastic) cup*	*(plastic) cup*	*cup*
RU	*stakan*	*(plastic) stakan*	*(plastic) chashka*	*chashka*

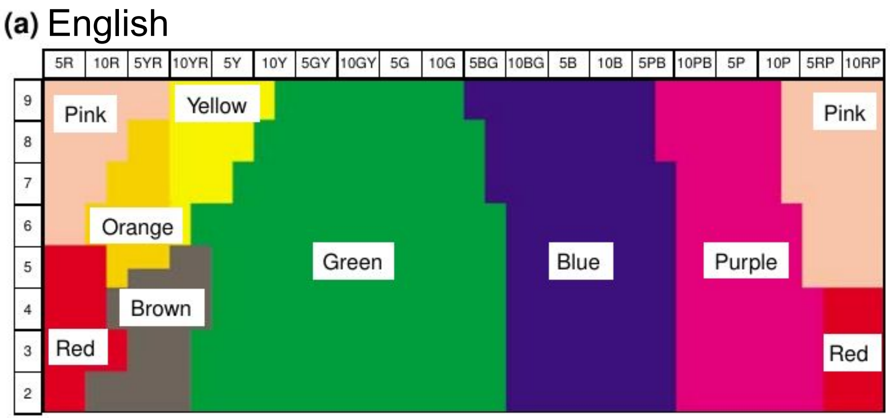
based on [Pavlenko & Malt, 2011]

Color Categories across Languages

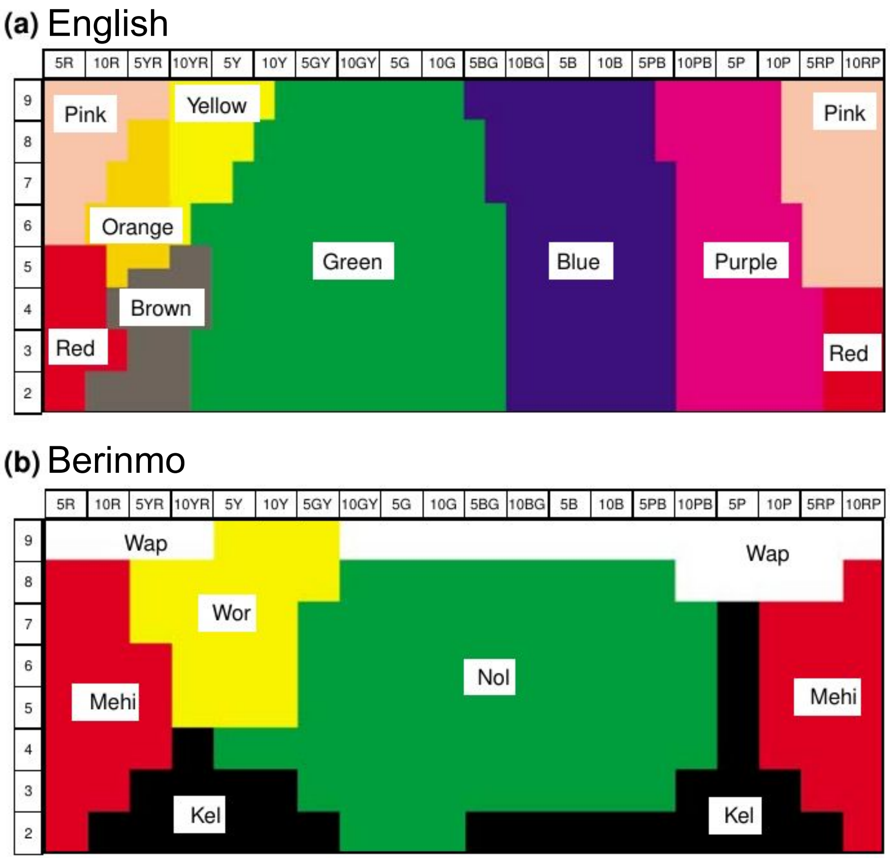
Color naming task: show color chips one by one and ask to name each.



Munsell color chart



[Kay & Regier, 2006]



[Kay & Regier, 2006]

Linguistic Relativity

- “The Sapir-Whorf hypothesis”.
- Our thoughts are influenced by the language(s) we speak.
- Controversial: results both in favour and against.

Category Effects in Color Memory

Category Effects in Color Memory

- [Cibelli et al., 2016] (link): is color memory language-specific?

- Two studies:
  - Color reconstruction + goodness rating (with English speakers).
  - Color discrimination + goodness rating (with speakers of three languages).

Category Effects in Color Memory

- [Cibelli et al., 2016] (link): is color memory language-specific?

- Two studies:
  - Color reconstruction + goodness rating (with English speakers).
  - Color discrimination + goodness rating (with speakers of three languages).

- A formal model fitted to the experimental data.

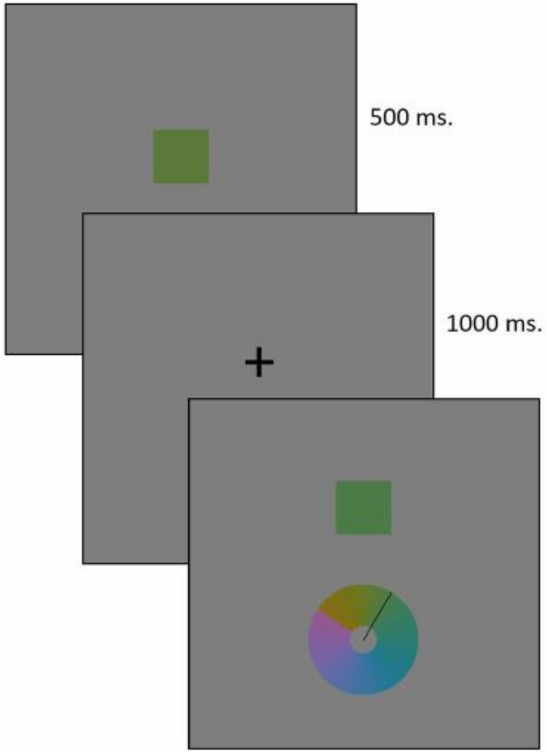
Color Memory Experiment

Experiment 1a:

1. Look at a color chip.

2. Wait 1 second.

3. Pick the same color on a color wheel.

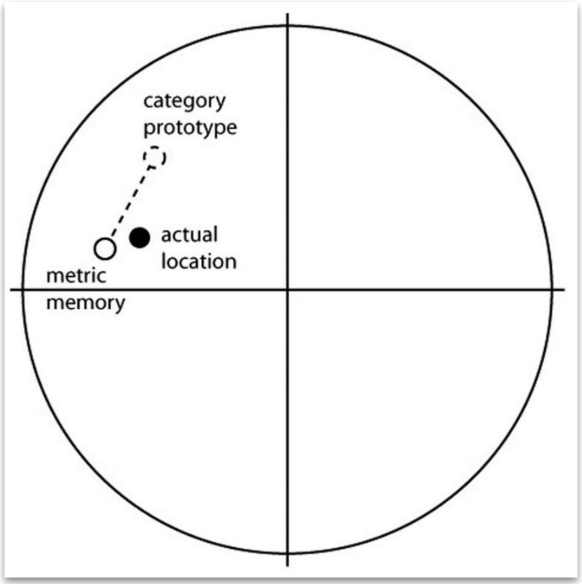


Categorical Perception across fields

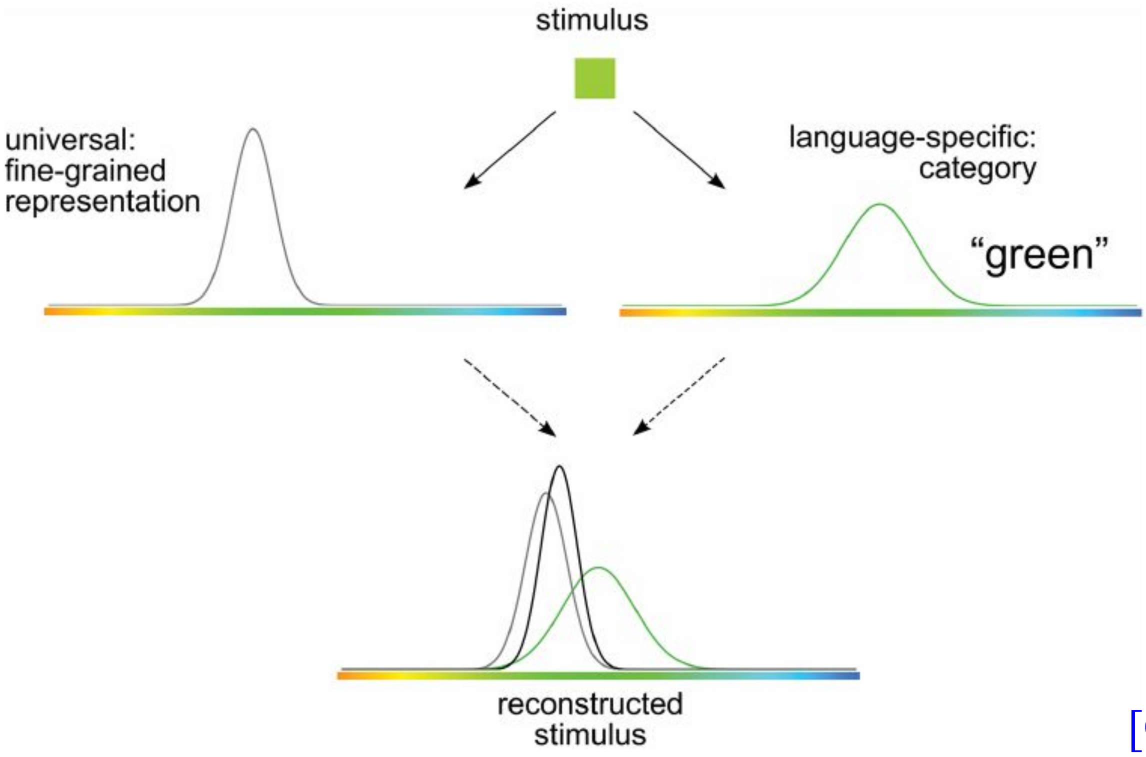
- Categories are structured, with a prototype somewhere in the center.

- Sound perception: it is easier to detect changes in non-prototypical variants of sound [i] than in variants close to the prototype. [Kuhl, 1991]

- Spatial perception: when reconstructing a stimulus from memory, we bias it towards the prototype.



Categorical Perception for color



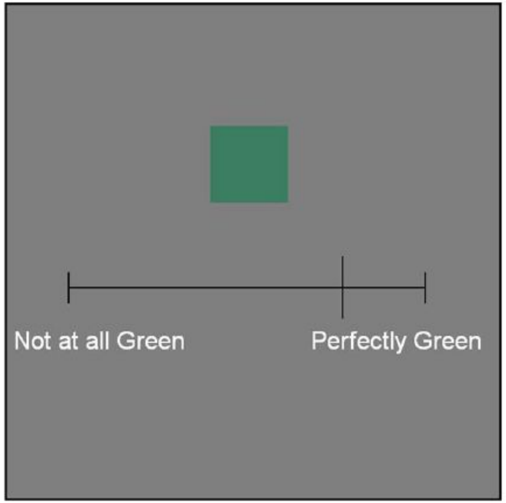
[Cibelli et al., 2016]

Color Memory Experiment + Goodness Rating

Experiment 1a:

1. Look at a color chip.
2. Wait one second.
3. Pick the same color on a color wheel.

Experiment 1b: rate how good this example of green/blue is



Category Adjustment Model

Notation:

- S: perceived color stimulus
- M: memory of the stimulus
- c: color category of the stimulus
- $\hat{s}$: reconstructed stimulus

[Cibelli et al., 2016]

Category Adjustment Model

S:	color stimulus
M:	memory
c:	color category
ŝ:	reconstructed stimulus

Reconstructed stimulus:

$$\hat{s} = E[S|M, c]$$

[Cibelli et al., 2016]

Category Adjustment Model

S:	color stimulus
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Reconstructed stimulus:

$$\hat{s} = E[S|M, c]$$

Posterior distribution:

$$p(S|M, c) \propto p(M|S, c)p(S|c) \qquad \text{[Bayes' rule]}$$

$$\propto p(M|S)p(S|c) \qquad \text{[because } M \text{ is independent of } c \text{ given } S\text{]}$$

[Cibelli et al., 2016]

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Stimulus "interpretation" is a Gaussian (modeling category effects):

$$p(S|c) = \mathcal{N}(S; \mu_c, \sigma_c^2)$$

values from Exp. 1b

[Cibelli et al., 2016]

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values from Exp. 1b

Memory is also a Gaussian (modeling uncertainty):

$$p(M|S) = \mathcal{N}(M; \mu_m, \sigma_m^2)$$

values from Exp. 1a

[Cibelli et al., 2016]

Model Versions

S:	color stimulus
M:	memory
c:	color category
ŝ:	reconstructed stimulus

Model versions:

1. Baseline model, no category influence on reconstruction:

$$p(S|M, -) \propto \mathcal{N}(M; \mu_m, \sigma_m^2)$$

[Cibelli et al., 2016]

Model Versions

S:	color stimulus
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Model versions:

1. Baseline model, no category influence on reconstruction:

$$p(S|M,-) \propto \mathcal{N}(M;\mu_m,\sigma_m^2)$$

2. One-category models, influence of either *green* or *blue*:

$$p(S|M,c) \propto \mathcal{N}(M;\mu_m,\sigma_m^2)\,\mathcal{N}(S;\mu_c,\sigma_c^2)$$

[Cibelli et al., 2016]

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3. Two-category model, influence of both *green* and *blue*:

$$p(S|M) = \sum_{c \in \{c_1, c_2\}} p(S|M, c)\pi(c)$$

[Cibelli et al., 2016]

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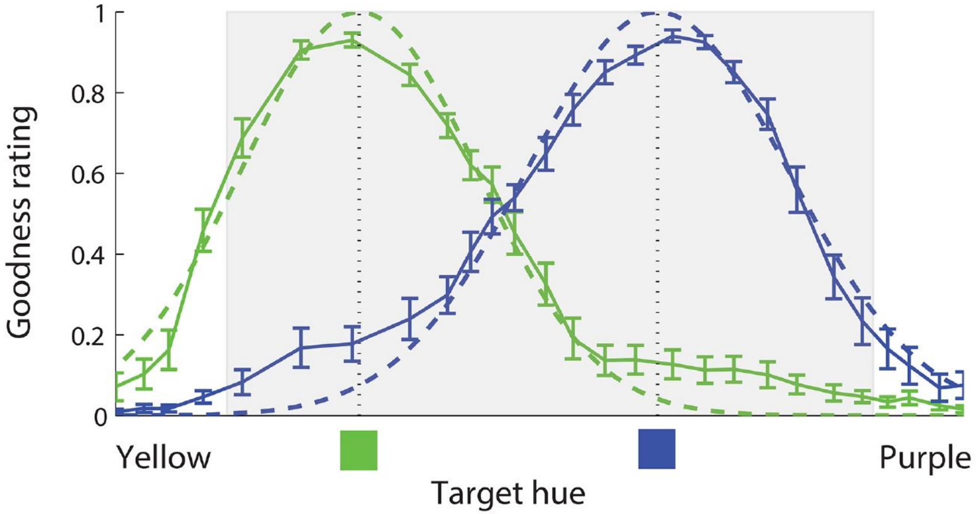
$\propto p(S = s|c)$; "applicability" of *c* to *S*

[Cibelli et al., 2016]

Applying the Model

Fitting the models:

1. Use goodness data (Exp. 1b) to fit the parameters of Gaussian functions for each category.



[Cibelli et al., 2016]

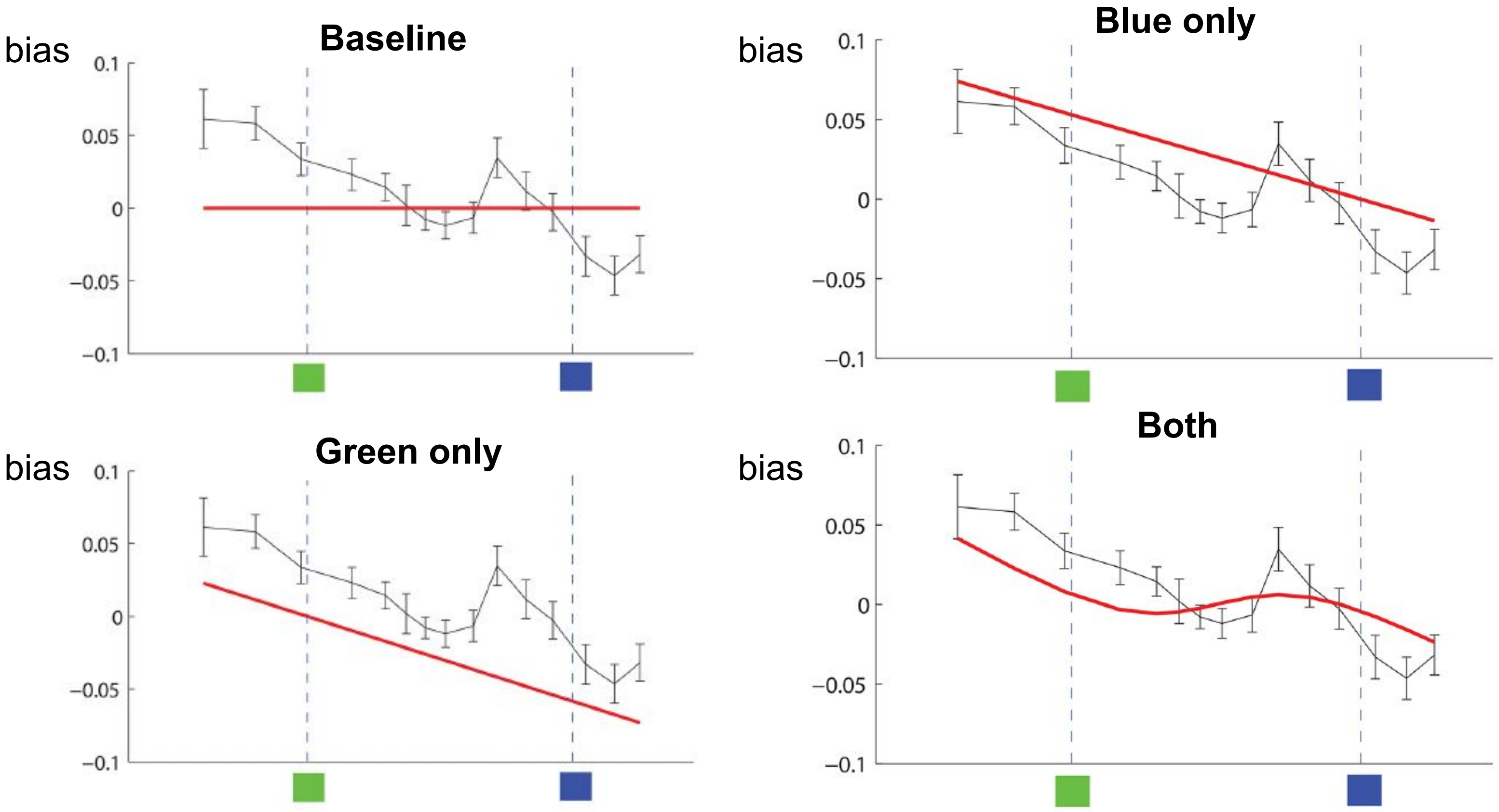
Applying the Model

Fitting the models:

1. Use goodness data (Exp. 1b) to fit the parameters of Gaussian functions for each category.

2. Use reconstruction data (Exp. 1a) to fit the parameters of Gaussian function for memory uncertainty.

[Cibelli et al., 2016]



[Cibelli et al., 2016]

Measure	Null	1-cat. (G)	1-cat. (B)	2-cat.
LL	1860	1650	1900	**1980**
MSE	0.00099	0.00160	0.00061	**0.00042**

Study 1: Summary

Testing the core assumption of the Category Adjustment Model.

- Color memory + goodness rating experiment.

- Color reconstruction is influenced by (1) universal color perception and (2) language-specific color categories.

- Both adjacent categories (*green* and *blue*) affect reconstruction.

Category Adjustment across Languages

Study 2: testing the model cross-linguistically.

- The goal is to look into linguistic relativity.

- One option: similar reconstruction data for other languages.

- Alternative: a different task, color discrimination.

Color Discrimination Experiment

Experiment 2: color discrimination.

1. Look at a color chip for 5 seconds.

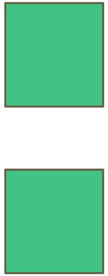
2. Wait 30 seconds.

3. Choose which of the two (new) stimuli matches the one before.

Color Discrimination Experiment

Existing results [Roberson et al., 2000]:

1. It's easier to discriminate colors <u>across</u> categories (e.g., *blue* vs. *green*) than <u>within</u> a category (e.g., a *green* vs. another *green*).



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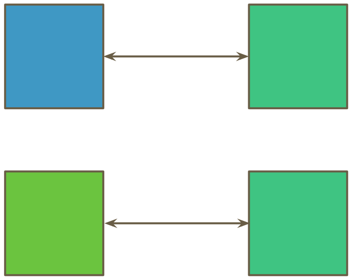

Color Discrimination Experiment

Existing results [Roberson et al., 2000]:

1. It's easier to discriminate colors across categories (e.g., *blue* vs. *green*) than within a category (e.g., a *green* vs. another *green*).

2. Within a category, it's easier to discriminate between two colors when the first one is "good" (and second is "bad"), than vice versa.

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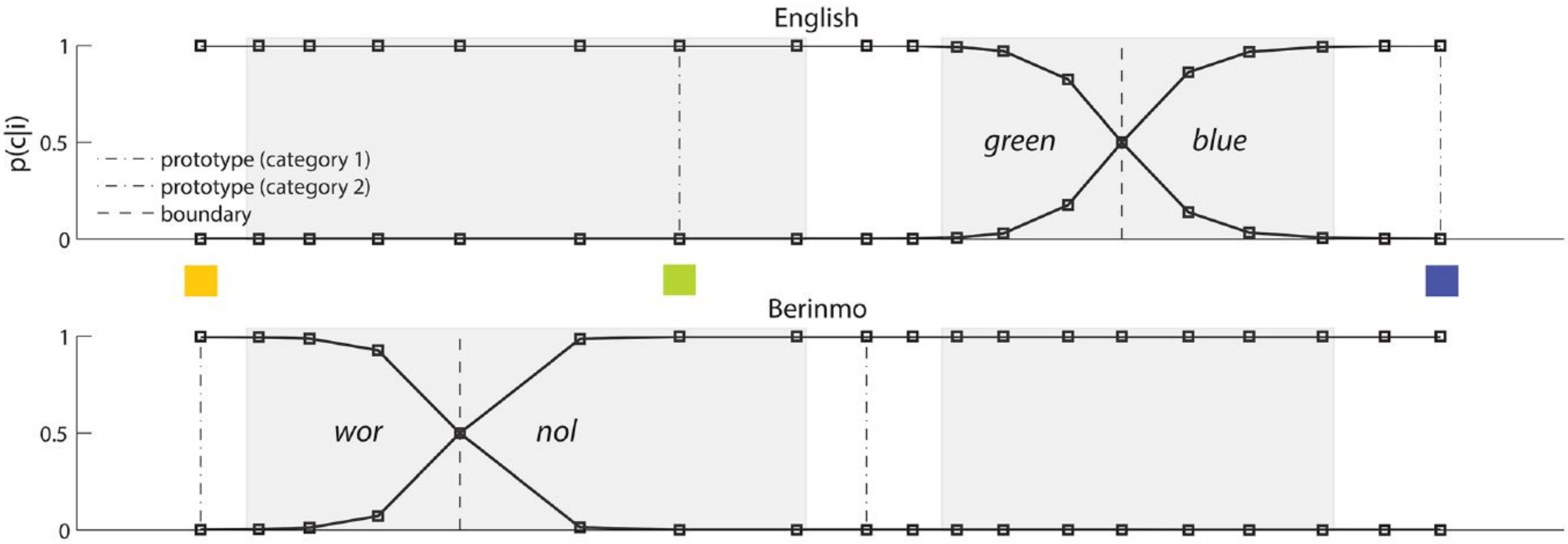
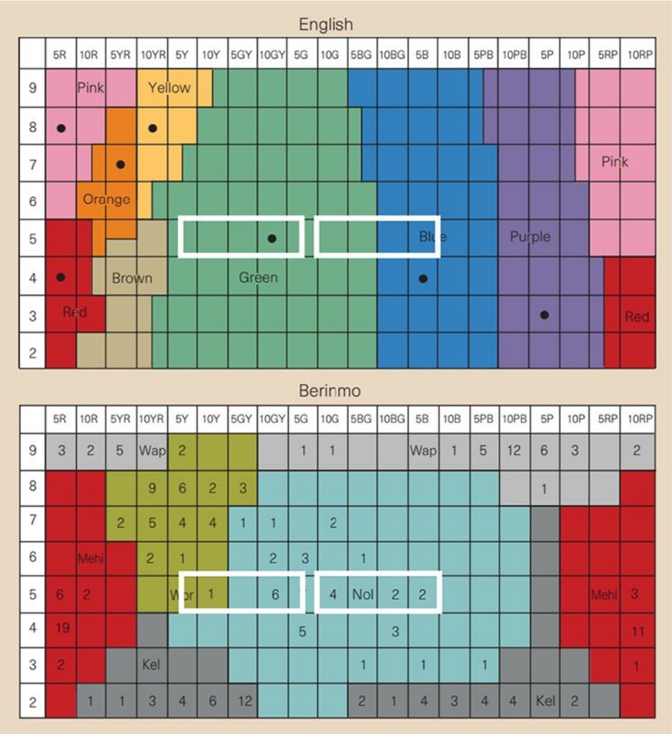
3. Discrimination patterns are language-specific.



Color naming in English and Berinmo.

[Cibelli et al., 2016]

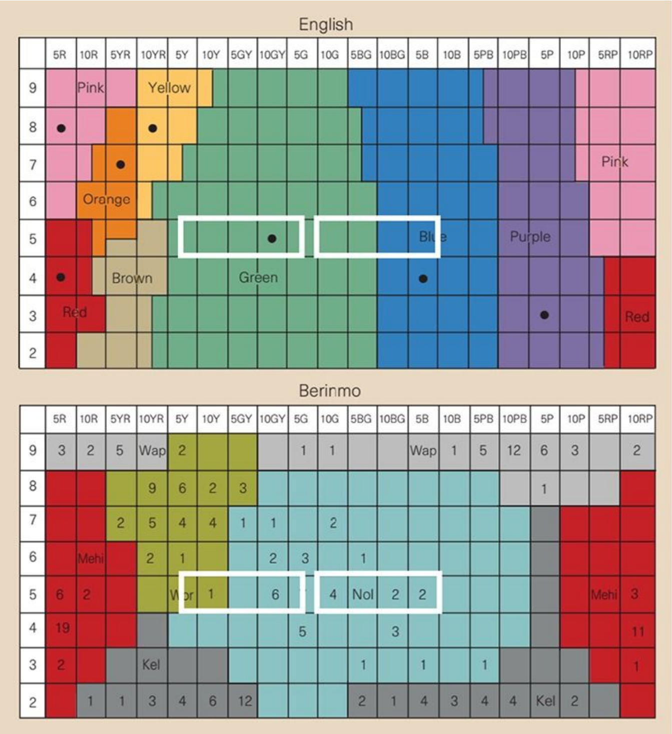


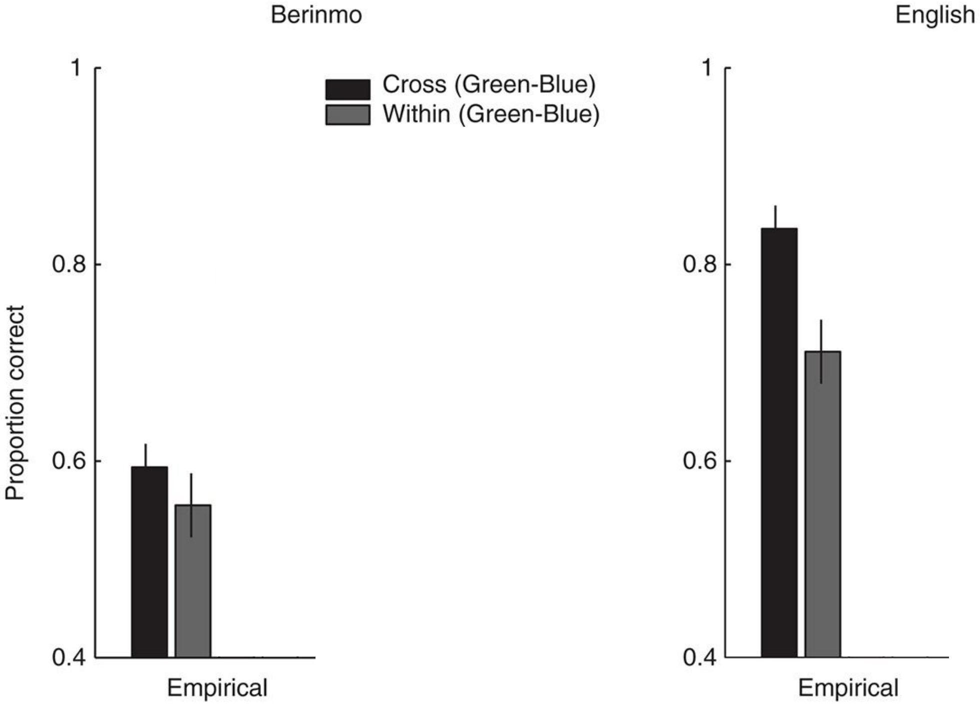
Left panel:
- ‘within’ (*green*) in English
- ‘across’ (*wor-nol*) in Berinmo

Right panel:
- ‘across’ (*green-blue*) in English
- ‘within’ (*nol*) in Berinmo

[Regier & Xu, 2018]

Discrimination result 1: across easier than within.





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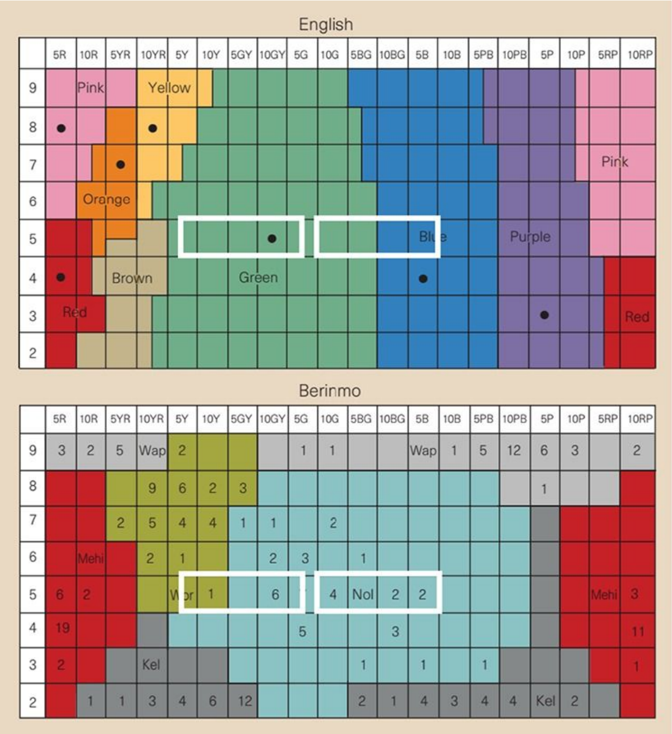

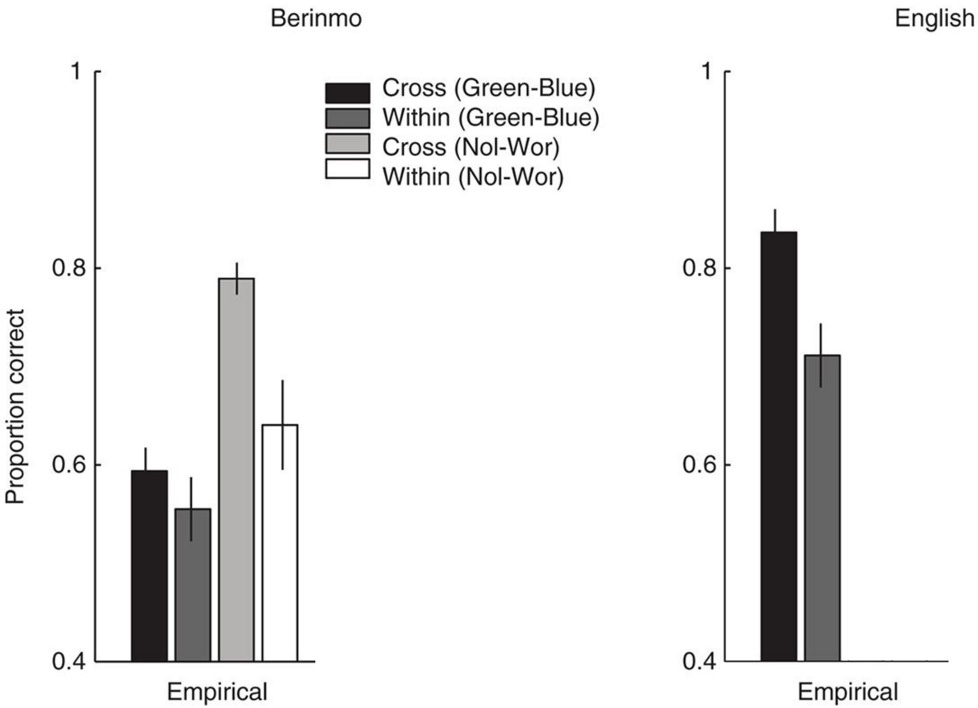

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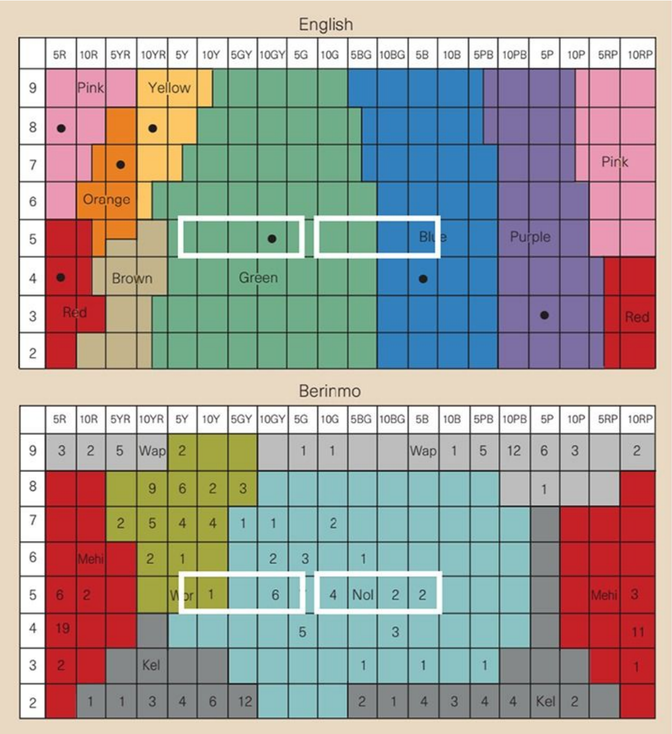
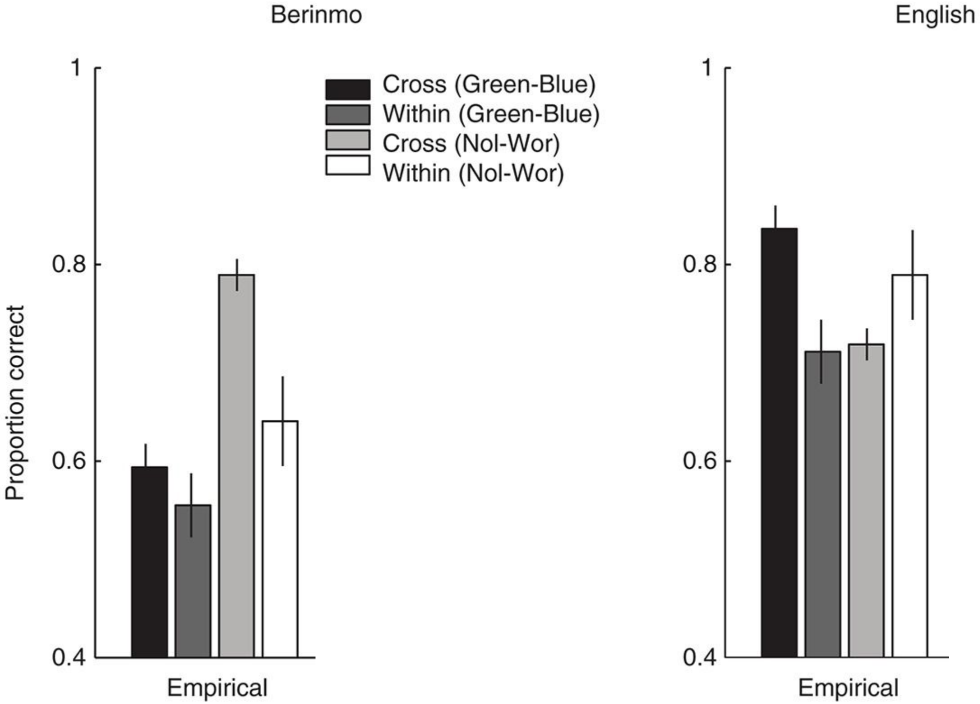
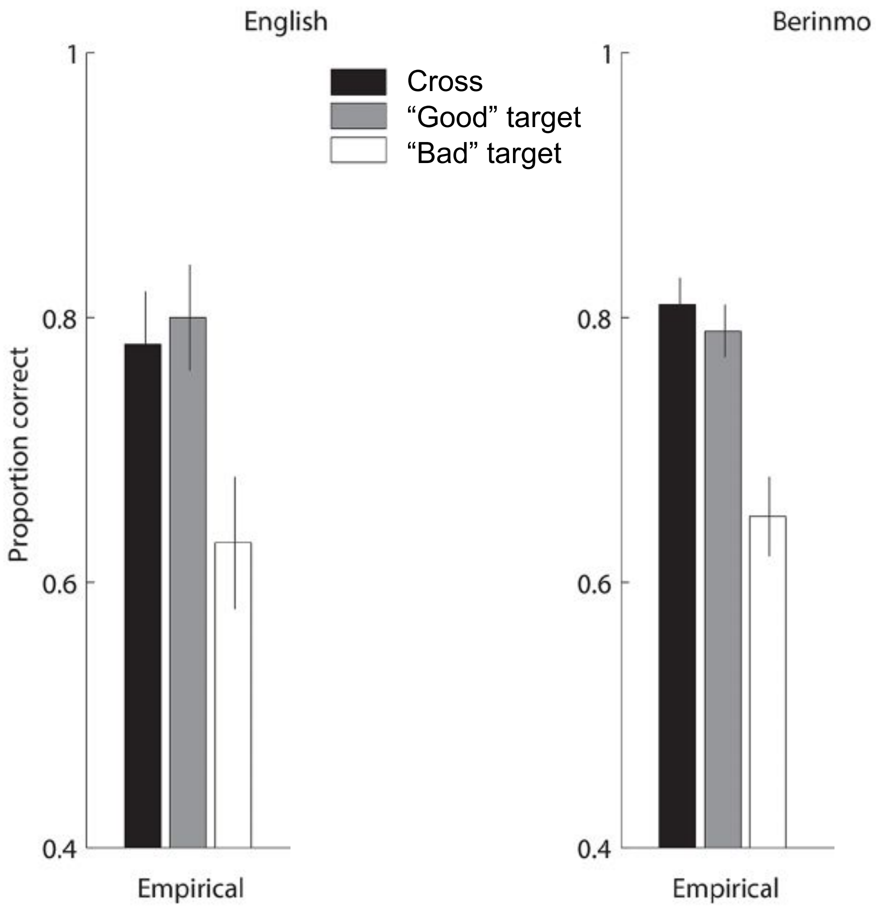




[Regier & Xu, 2018]

Discrimination result 2: good target is easier than bad target.



[Cibelli et al., 2016]

Applying CAM to discrimination data

Probability of the correct choice:

$$p = \frac{sim(r,t)}{\sum_{i \in \{t,d\}} sim(r,i)}$$

i:	color stimulus
M:	memory
r:	reconstructed stimulus
t:	target stimulus
d:	distractor

Applying CAM to discrimination data

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The similarity between (1) *r* and *d*, and (2) *r* and *t:*

$$sim(i,j) = \exp\left(-dist(i,j)\right)$$

→ distance directly measured in a given color space

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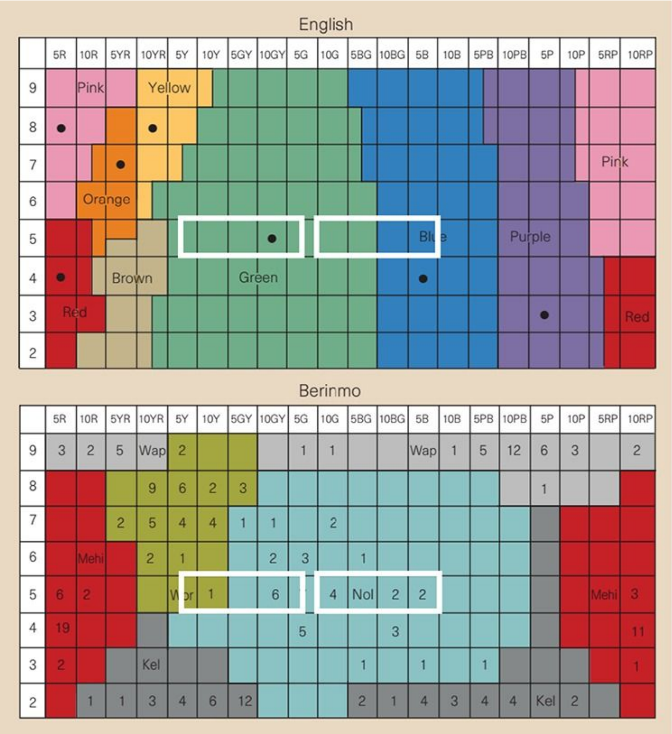
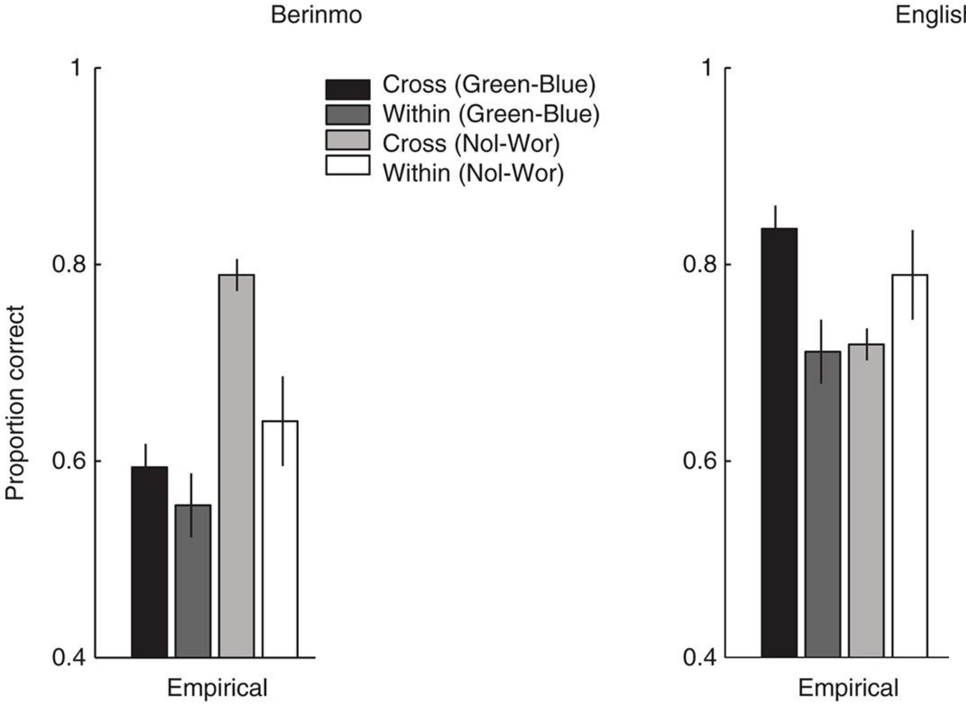
Reconstruction of the stimulus:

$$r = E[t|M] = E\left[\sum_{c \in \{c_1,c_2\}} p(t|M,c)\pi(c)\right]$$

→ category adjustment

Discrimination result 1: across easier than within.





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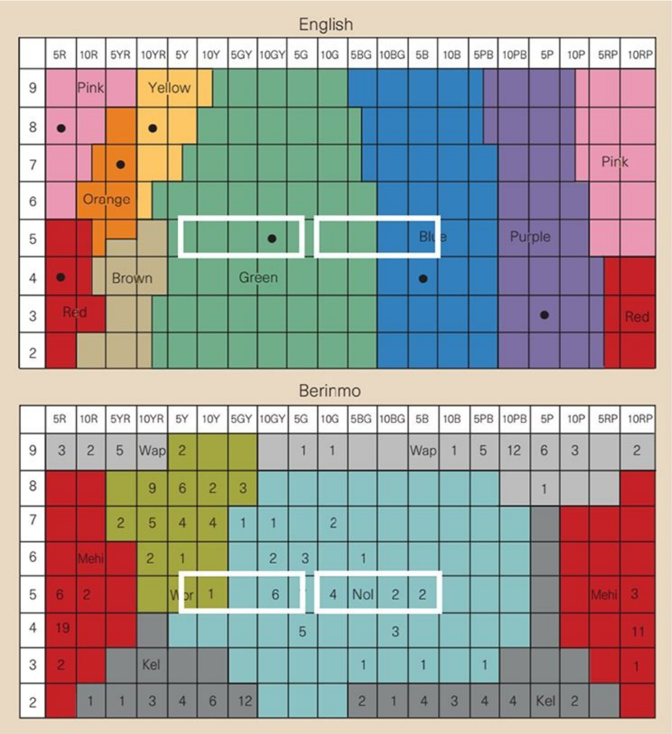

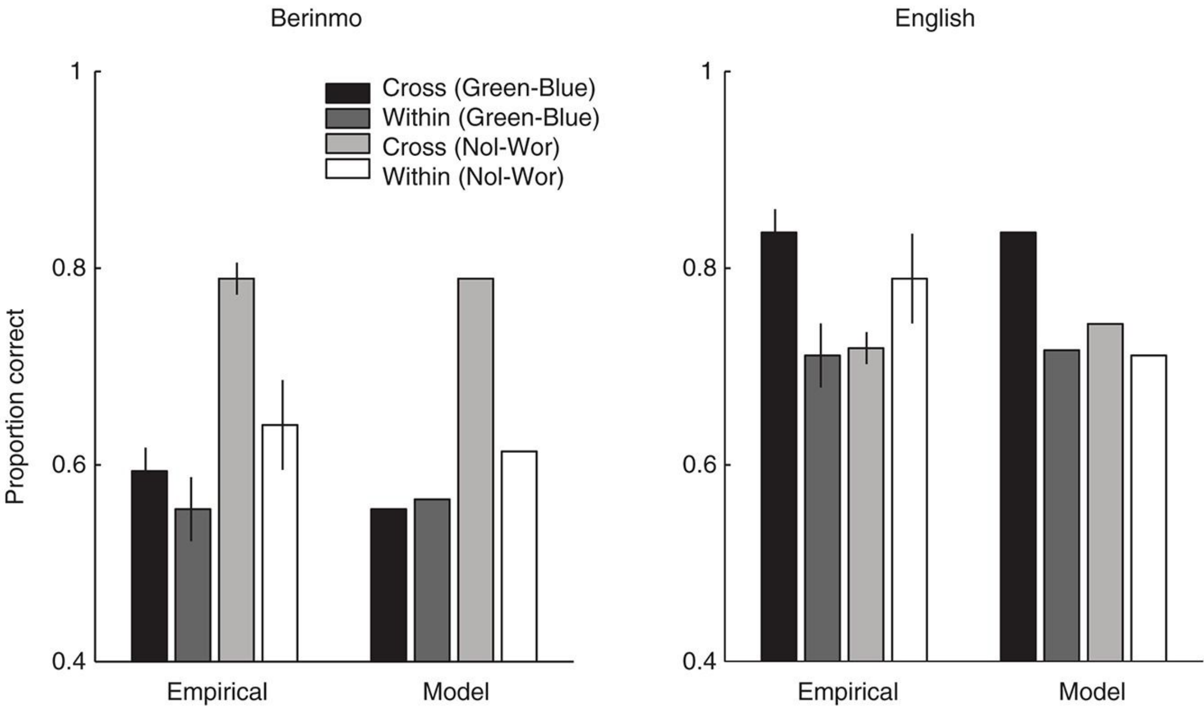

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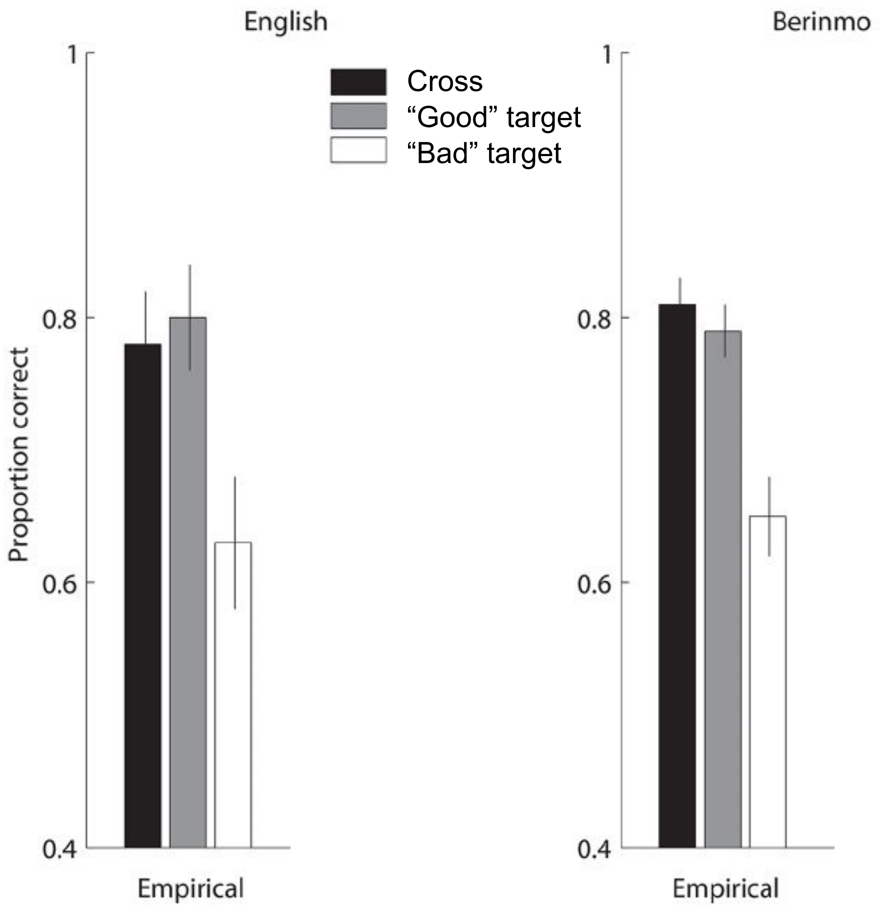
Discrimination result 2: good target is easier than bad target.



[Cibelli et al., 2016]

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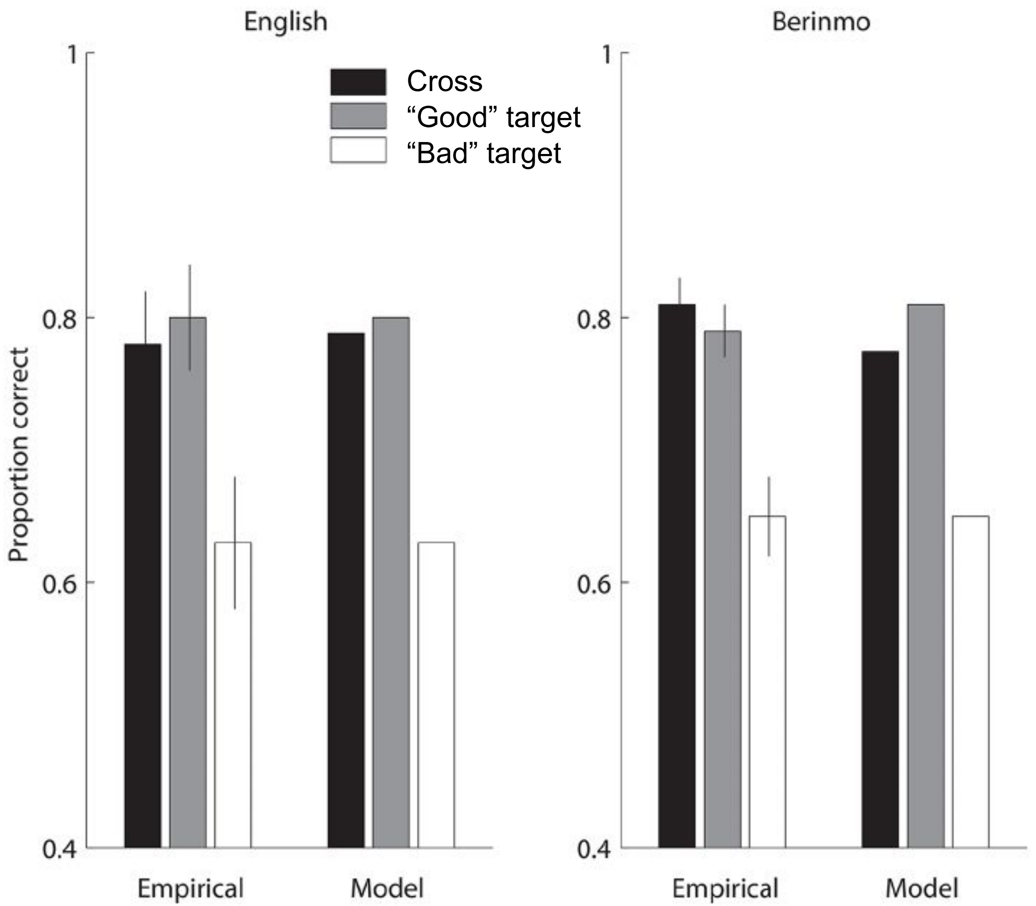


[Cibelli et al., 2016]

Category Effects in Color Memory

Summary of Study 2: Category Adjustment Model on cross-linguistic data.

1. This study expresses Linguistic Relativity in terms of probabilistic inference.

2. Category Adjustment Model accounts for language-specific partitionings of the color space in the human mind.

3. Color memory is inferred probabilistically from two sources: universal color perception and language-specific color categories.

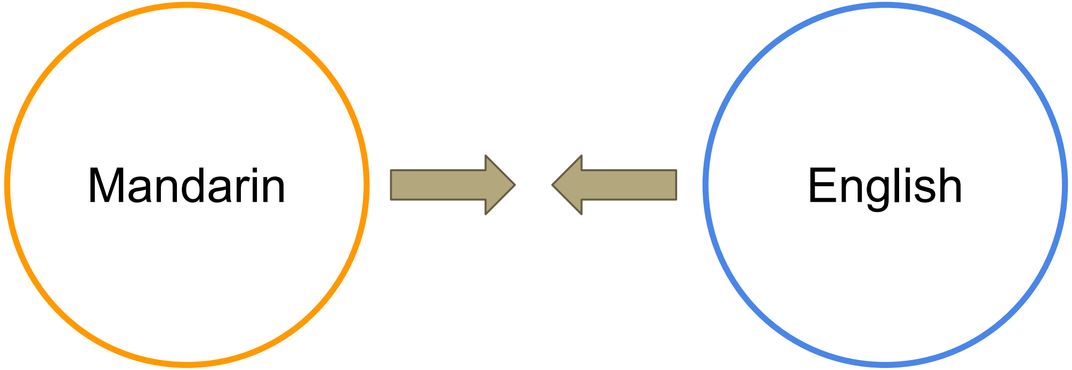
Category Adjustment in Bilingualism

Category Adjustment in Bilingualism

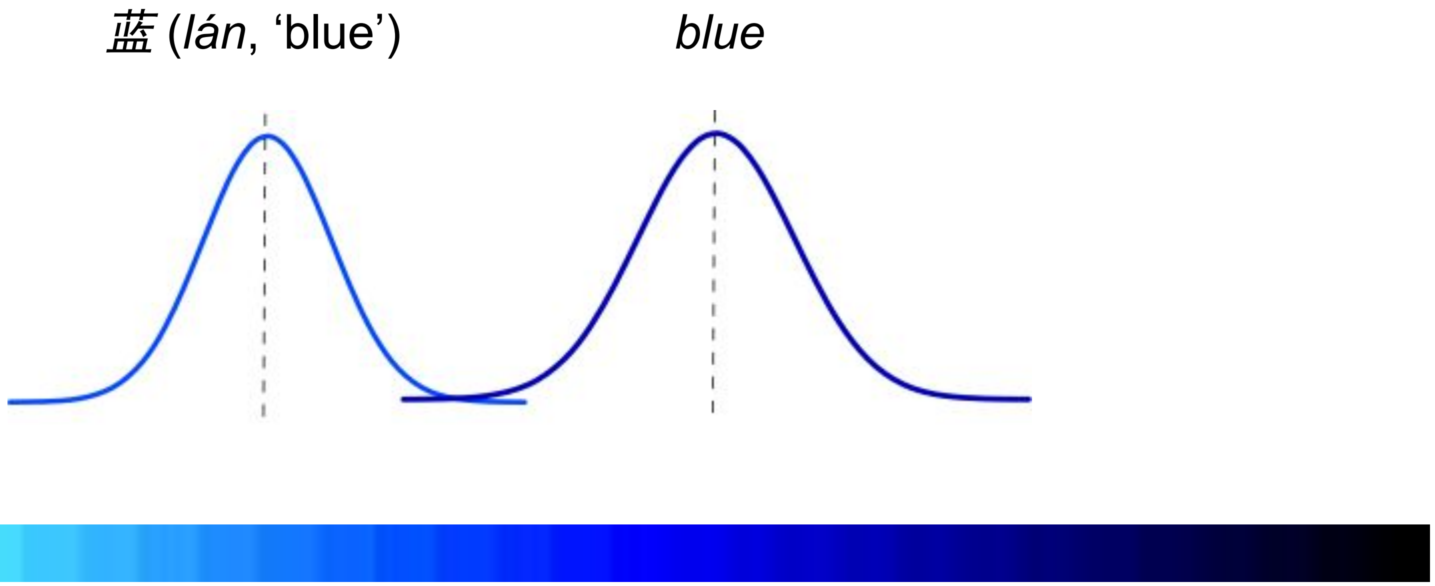
- Color categories are influenced by the speaker's language. But what about bilingual speakers?

- Category Adjustment Model has been extended to research in bilingualism (Matusevych et al., 2018; link).

Languages in the mind: Convergence

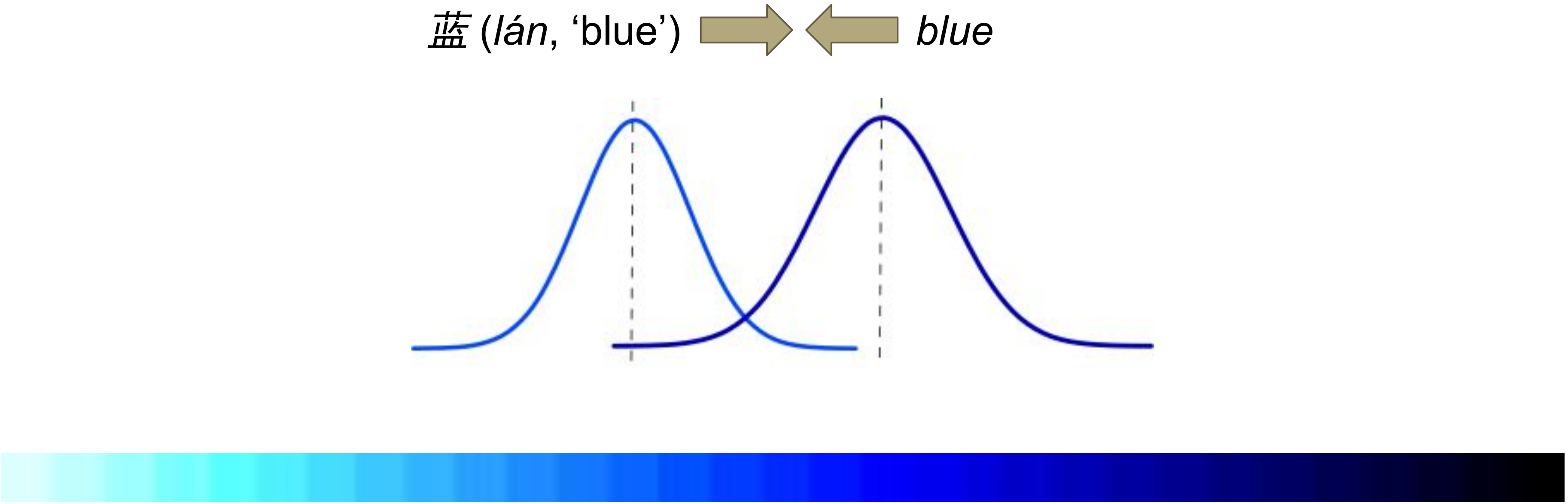


Conceptual categories in the mind



Two monolingual speakers

Conceptual shift



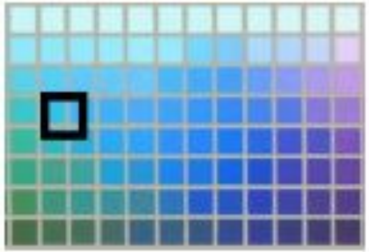
A bilingual speaker

Conceptual shift across domains

- Containers in Dutch-French bilingual speakers [Ameel et al., 2005, 2009]
- Emotions in Russian-English bilingual speakers [Pavlenko, 2002]
- Number in Japanese-English bilingual speakers [Athanasopolous, 2006]
- Both L1 and L2 categories “shift” in the representational space.

Focal color selection

Participants locate the focal area for each color term.



Mandarin
monolinguals
(Mandarin)

[Caskey-Sirmons & Hickerson, 1977]

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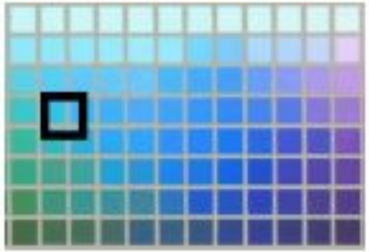
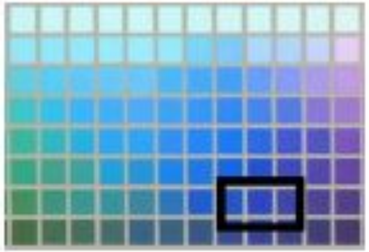


Mandarin monolinguals (Mandarin)

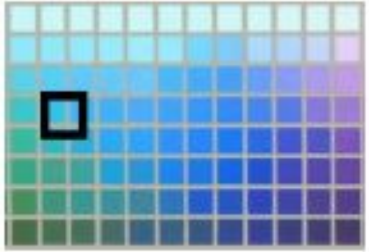


English monolinguals (English)

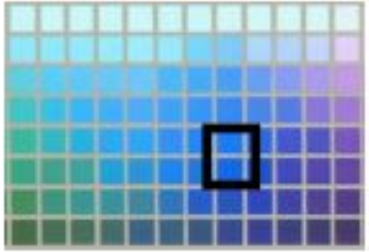
[Caskey-Sirmons & Hickerson, 1977]

Conceptual shift of L1 focal colors

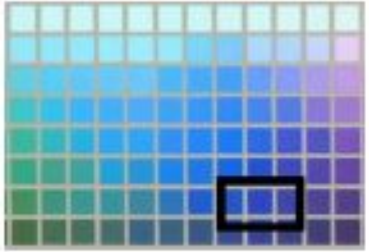
L1 colors appear shifted in bilinguals (compared to monolinguals)



Mandarin monolinguals (Mandarin)



Mandarin[L1]-English[L2] bilinguals (Mandarin)



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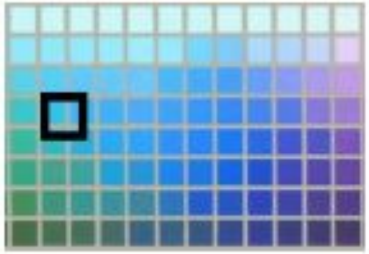
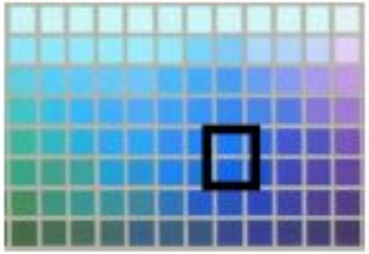
Conceptual shift of L1 focal colors

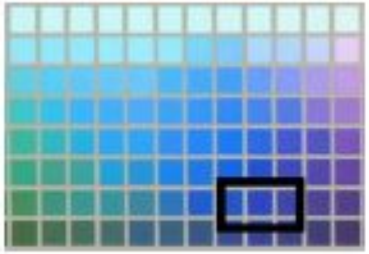
L1 colors appear shifted in bilinguals (compared to monolinguals)



Mandarin monolinguals (Mandarin)



Mandarin[L1]-English[L2] bilinguals (Mandarin)



English monolinguals (English)

[Caskey-Sirmons & Hickerson, 1977]

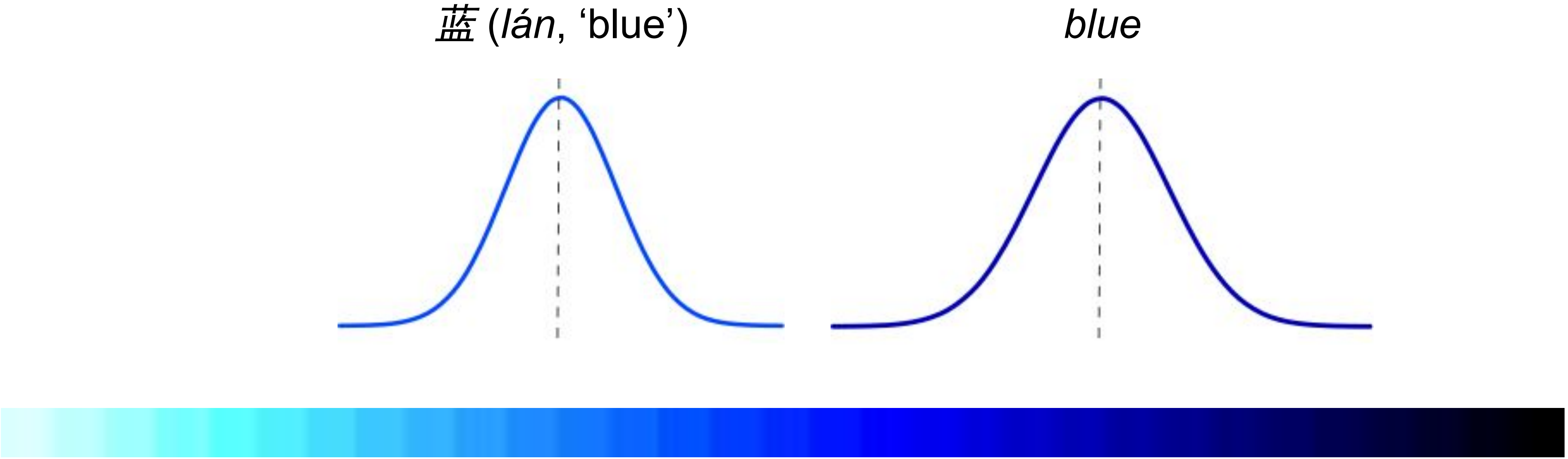
reverse transfer

Hypothesis

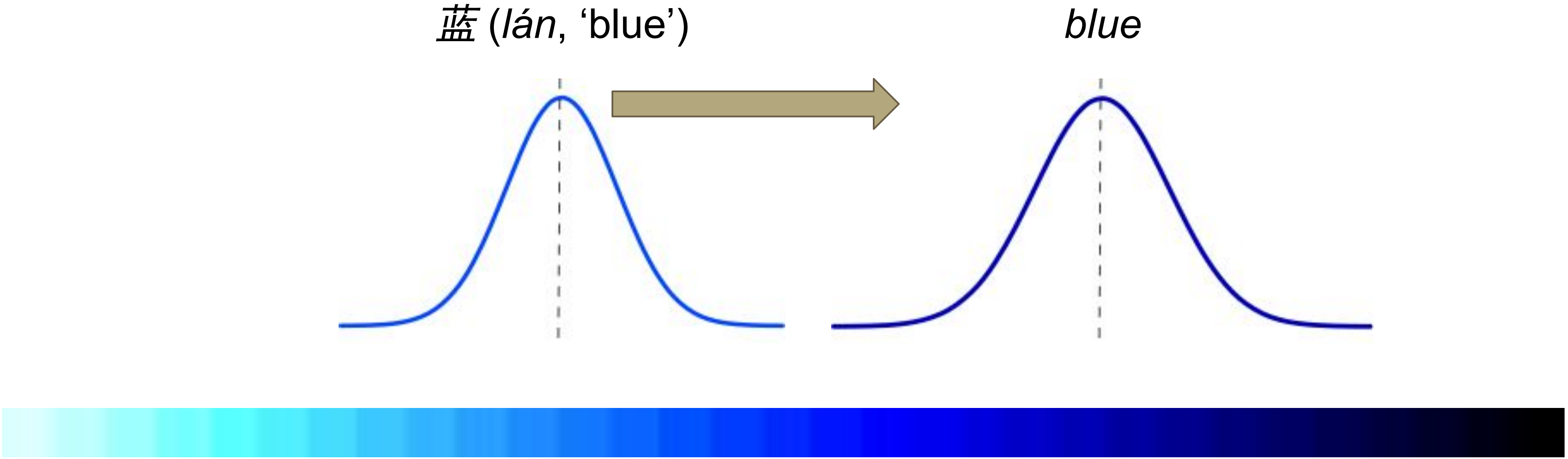
- Bilinguals' L1 color categories are a function of color categories in the two languages: L1 and L2.

- We formalize this idea using the Category Adjustment Model [Cibelli et al., 2016].

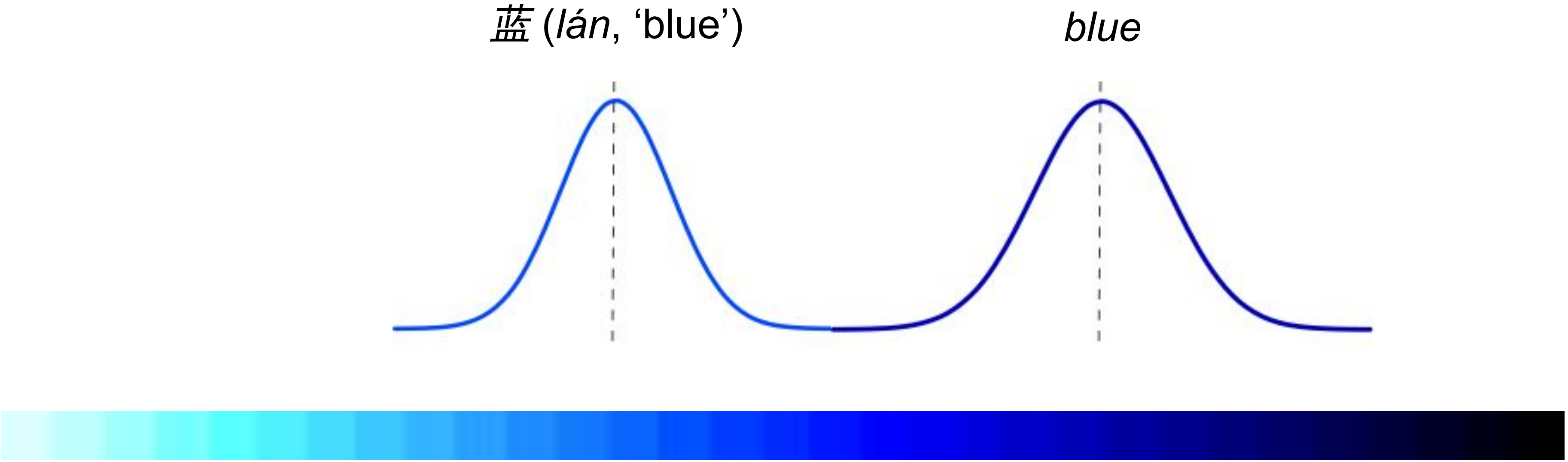
Category Adjustment Model: Our adaptation



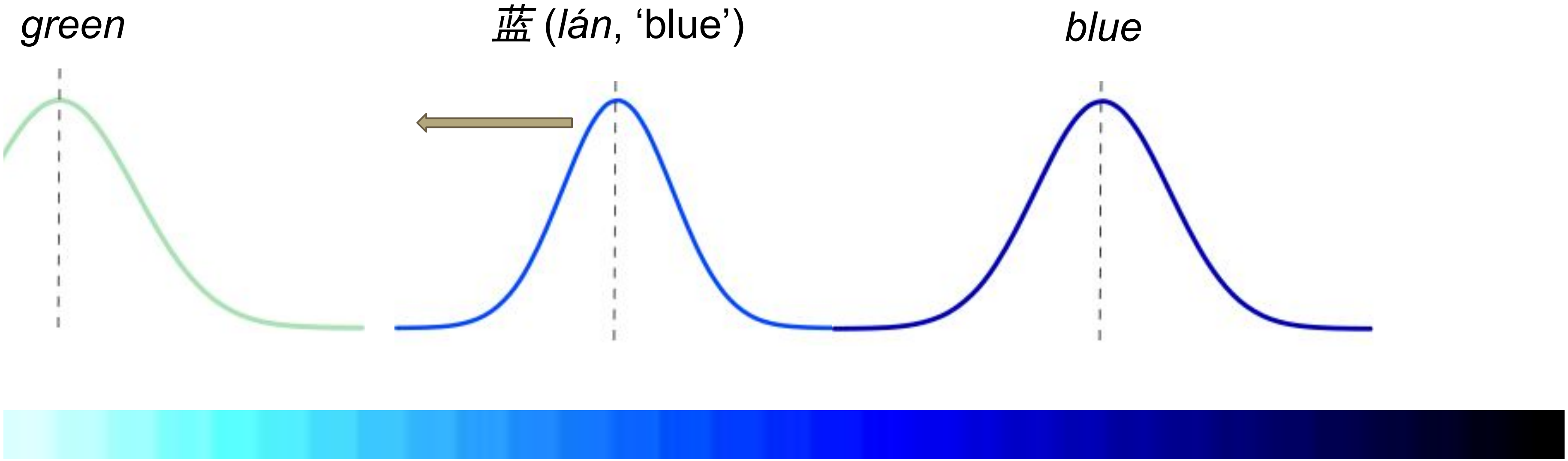
Category Adjustment Model: Our adaptation



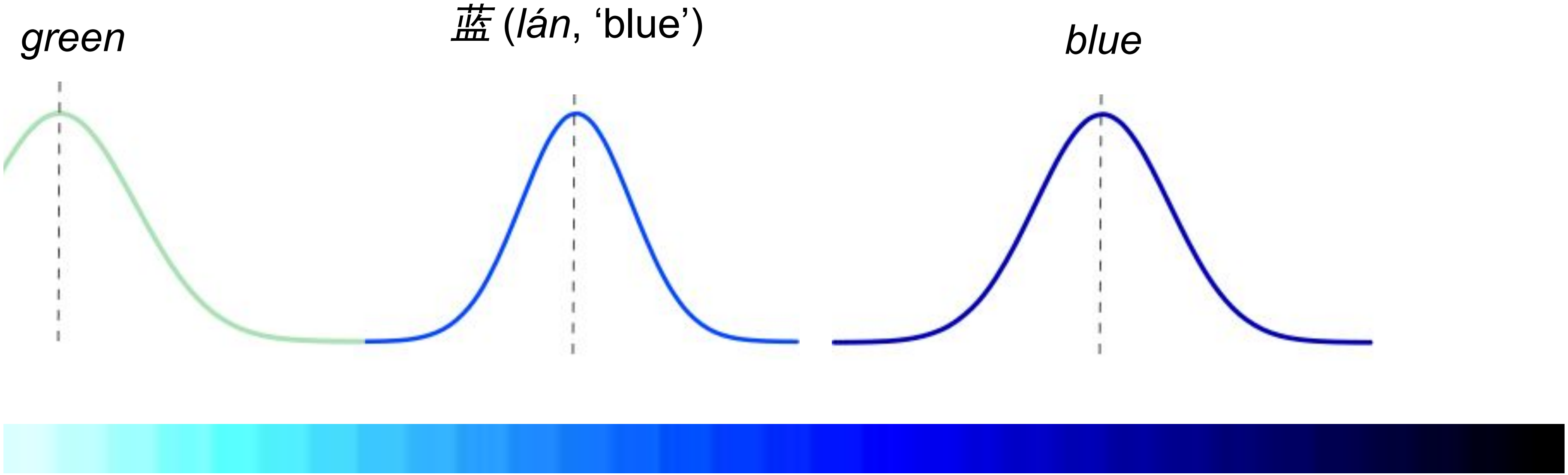
Category Adjustment Model: Our adaptation



Category Adjustment Model: Our adaptation



Category Adjustment Model: Our adaptation



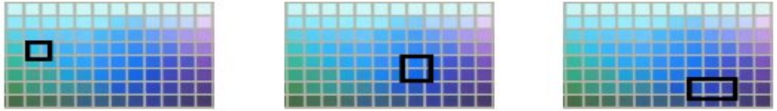
Category Adjustment Model: Prediction

- Consider one monolingual L1 category (e.g., Mandarin 蓝 [*lán*, ‘blue’])
- Consider all monolingual L2 categories (English *green, blue, red,* etc.)
- Shift the L1 category towards each L2 category (as a function of the distance between them).
- Outputs the adjusted (“bilingual”) L1 category.

Experimental data

Caskey-Sirmons & Hickerson, 1977: focal color selection

- English monolingual speakers: tested in English
- Monolingual speakers of 5 other languages:* tested in the respective language
- Bilingual speakers: one of the 5 languages + English: tested in the respective L1



* Korean, Japanese, Mandarin, Hindi, Cantonese

Conclusions

- Category Adjustment Model predicts bilingual L1 focal colors better than the monolingual baseline.

- Category Adjustment Model can be used to study cross-linguistic transfer.

Issues with this study

- Assumes an “end point” in second language learning.
- Does not simulate the learning process.
- Not compared to other theoretical accounts.
- Tested on one task from one experimental study.

Take-home

- Many theories related to language have not been formalized yet, and the field can benefit from cognitive modeling.
- Cognitive models need to take into account differences between languages.
- A good model should be tested on multiple experimental tasks and data sets.

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