Symbol grounding problem: How do children build up the lexicon?

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Symbol Grounding Problem
Steven Harnad (1990)

- Suppose you had to learn Chinese as a second language and the only source of information you had was a Chinese/Chinese dictionary. The trip through the dictionary would amount to a merry-go-round, passing endlessly from one meaningless symbol or symbol-string (the definientes) to another (the definienda), never coming to a halt on what anything meant.
- How can you ever get off the symbol/symbol merry-go-round? How is symbol meaning to be grounded in something other than just more meaningless symbols? This is the symbol ground problem.
-

- Individuals encounter things, must learn by trial and error what to do with what, and to do so, they must form internal representations that reliably sort things into their proper categories….
- First acquire an entry-level set of categories the honest way, like everyone else, but then assign them arbitrary names.
- Once the entry-level categories had accompanying names, the whole world of combinatory possibilities opened up and a lively trade in new categories could begin probably more in the spirit of barter than theft, and within a kin-line, one of sharing categories along with other goods.

- The symbol grounding problem is insightful and address problems infants face in lexical acquisition.
- But the solution Harnad proposes is far from satisfactory.
- He is wrong in some assumptions

Agreed: All words are “abstract”

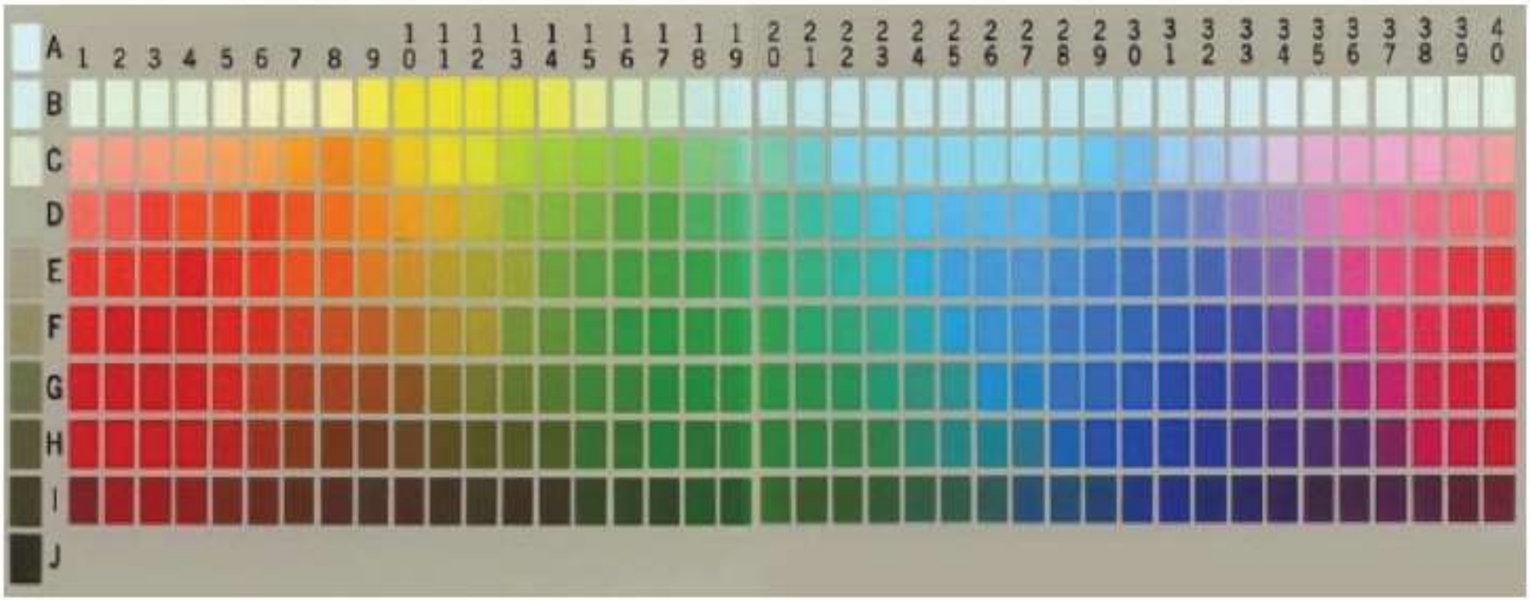
- Words pick up only a particular dimension from a very rich perceptual information.
- In that sense, abstractness of the meaning is orthogonal to having perceptible referents

"Moony" problem
(or Quine's Gavagai problem)

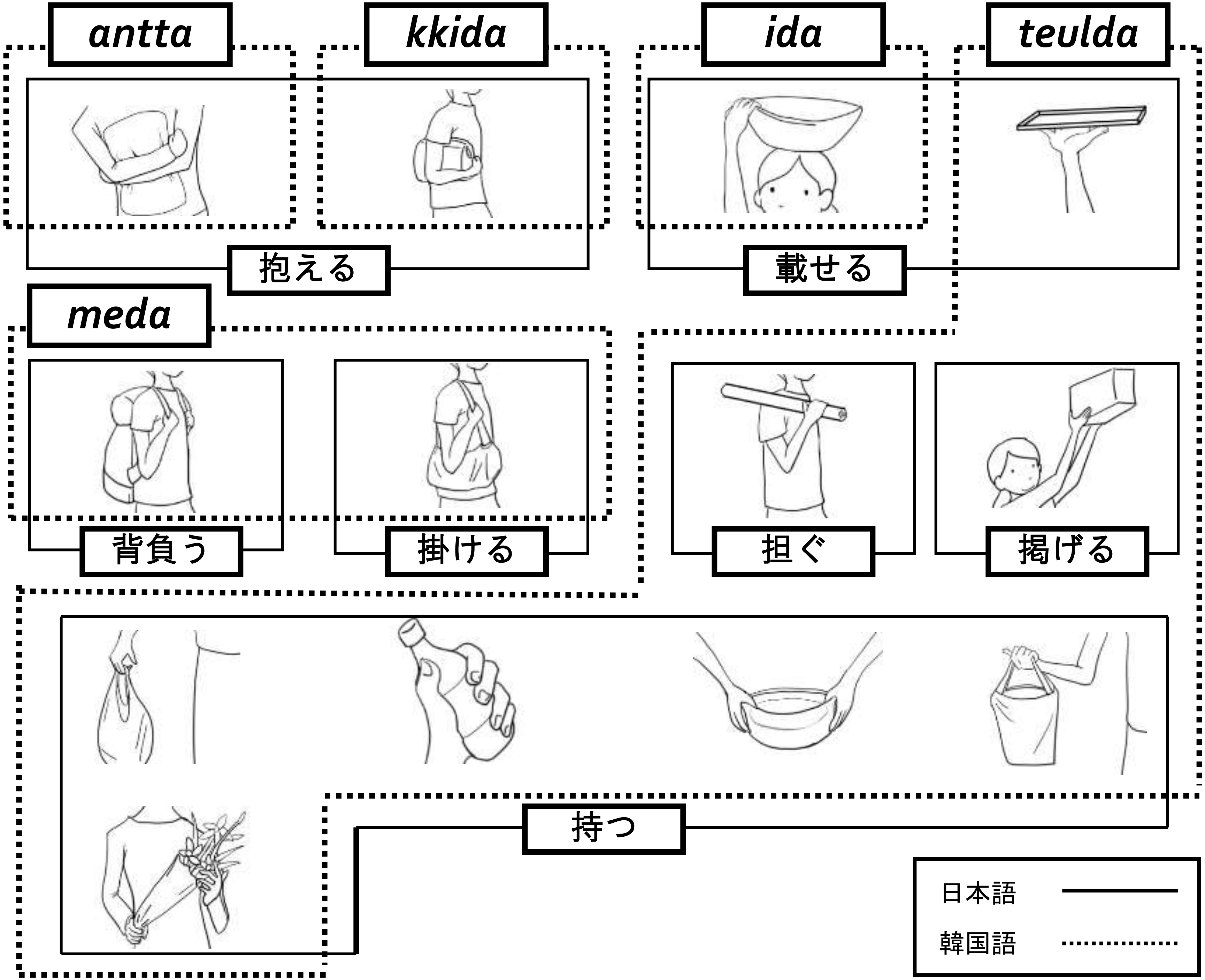
Symbol Grounding is not simply the problem of hooking the elementary concepts to arbitrary names

- Each word is an element of a vast and complex system
- The meaning of a words cannot be determined on its own, but is determined in relation to neighboring words in a given language

The meaning of “blue”



- Although ”blue” in English and “ao” in Japanese are assumed to be translation equivalents, their boundaries are different
- Many languages of the world do not even distinguish “blue” and “green”



antta
kkida
ida
teulda
抱える
載せる
meda
背負う
掛ける
担ぐ
掲げる
持つ
日本語
韓国語

Challenge children face in lexical acquisition

- Gavagai problem
  - Finding the invariants (basis for generalization) from a single or a limited number of exemplars
- System building problem
  - The meaning of a word can not be determined without knowing other words surrounding that word
  - Yet children are not likely to know other surrounding words

Key questions that need to be considered for the symbol grounding problem

1. How do infants first hook sensory/perceptual experiences onto language? How do they even realize speech sounds refer and have meanings?
2. How do children build up the system of adult lexicon without knowing the end state of the system?
3. What kind of cognitive capacities make this process possible?

Problem #1
How do they get the first grip of language?

- Make use of non-arbitrary relationship between sounds and meaning

In the traditional view of language

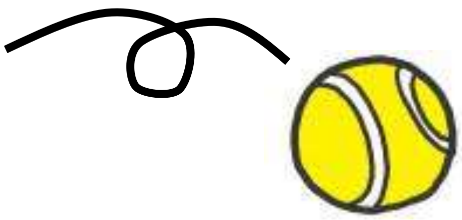
- The relation between word form and meaning is arbitrary.

- However…

mimetics, expressives, ideophones

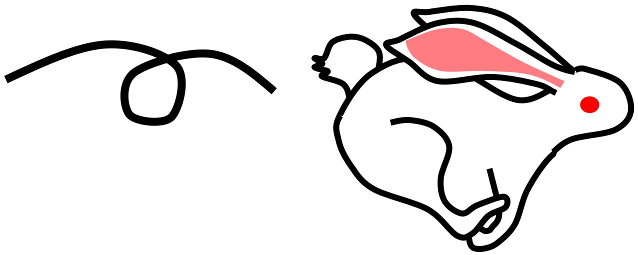
Many languages like Japanese contain a special class of sound-symbolic words in the lexicon (e.g., mimetics).

<u>Examples of Japanese mimetics:</u>



"*korokoro*"
(a light object rolling)

"*gorogoro*"
(a heavy object rolling)



"*pyonpyon*"
(a light object hopping)

FACTS

- Even conventional vocabulary contain systematicity between sound and meaning
- Early acquired words have higher systematicity between word sound and meaning (Monahan et al., 2014)
- In Infant Directed Speech, mothers use more onomatopoetic words and mimetics to younger children (Saji et al., 2013)

Sound Symbolism Bootstrapping Hypothesis

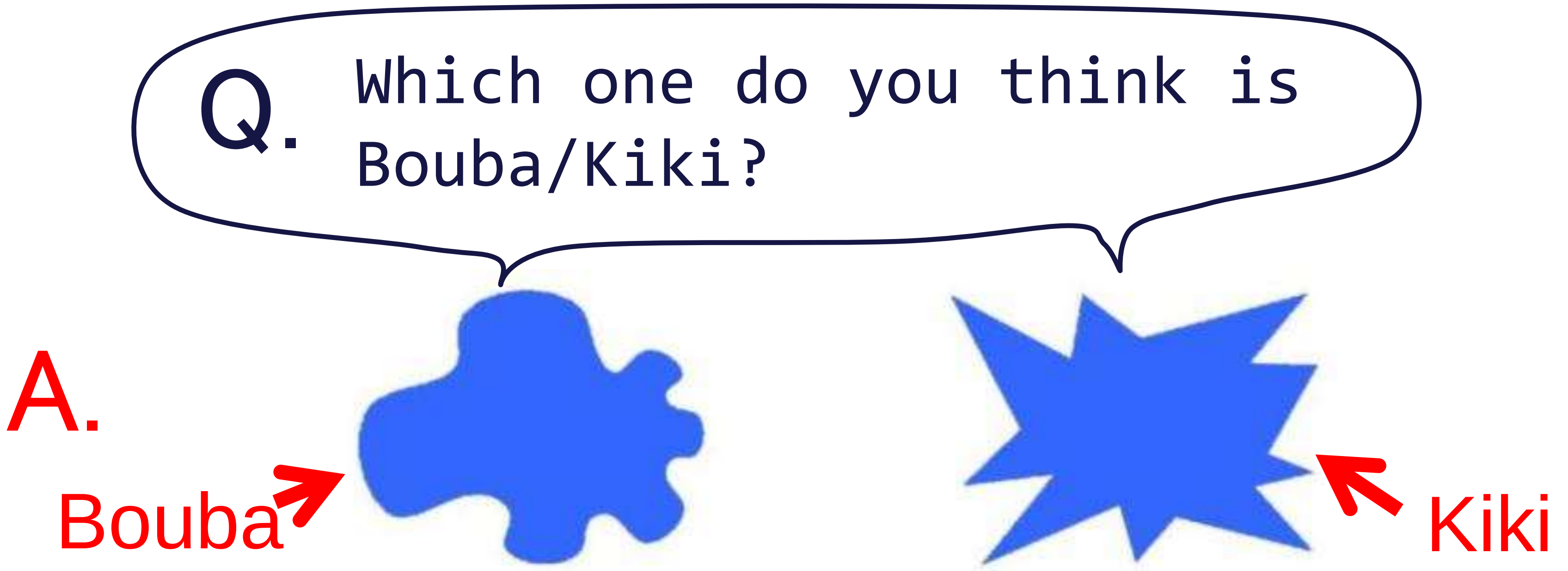
- Infants may be more sensitive to sound symbolism than adults because primary sensory cortical areas are less specialized in infants (e.g., Maurer et al., 2006; Ramachandran & Hubbard, 2001).
- Spontaneous synesthetic cross-modal binding may "give" infants the meaning of a novel word in speech.
- This may scaffold infants grasp that a word (a segment of speech sounds) has a meaning.

EEG Recordings with 11 month-olds (Asano et al., in press)

- Target age:
  11-~12-month-old preverbal infants

The Bouba-Kiki effect

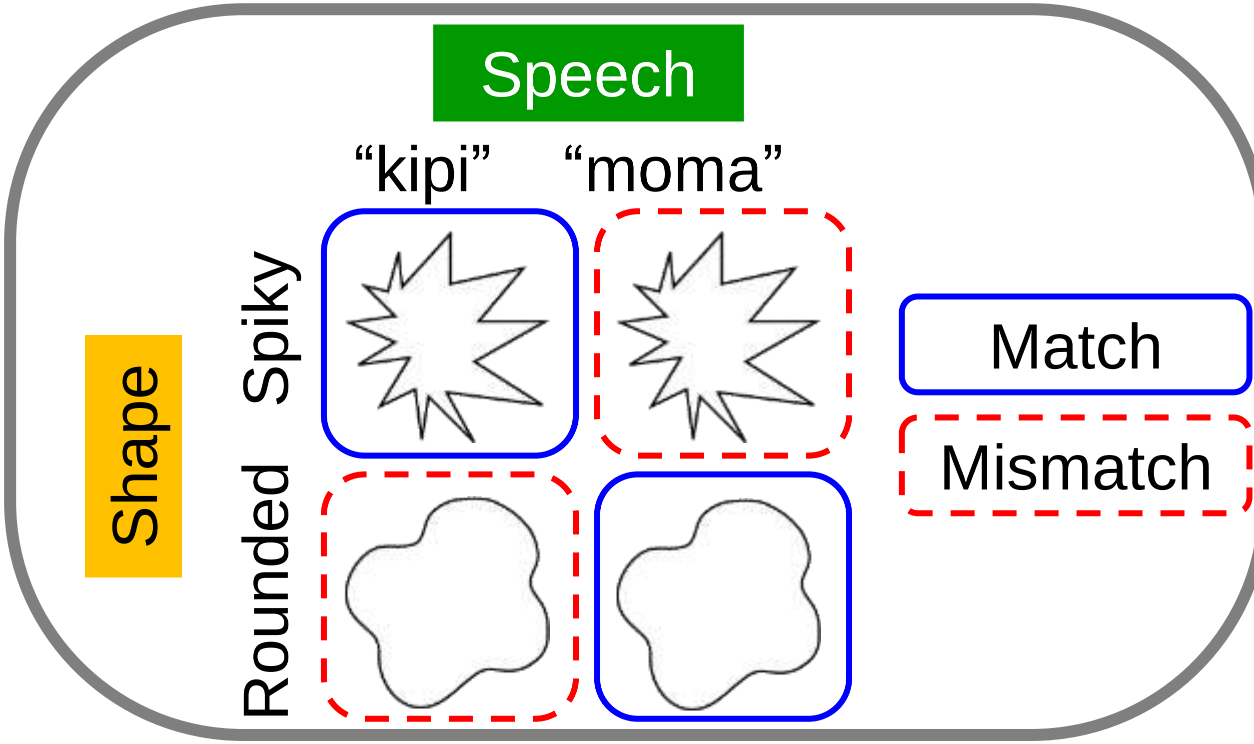
(*Köhler, 1929;* Ramachandran & Hubbard, 2001)

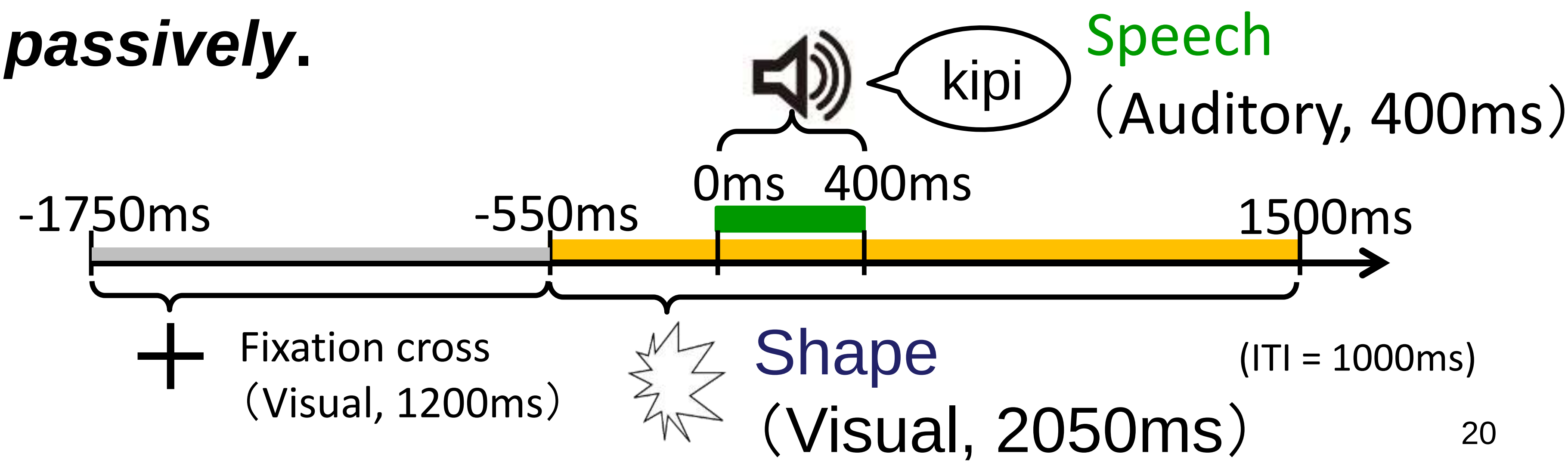


•2.5 year-olds demonstrate the bouba/kiki effect like adults (Maurer, et al., 2006).

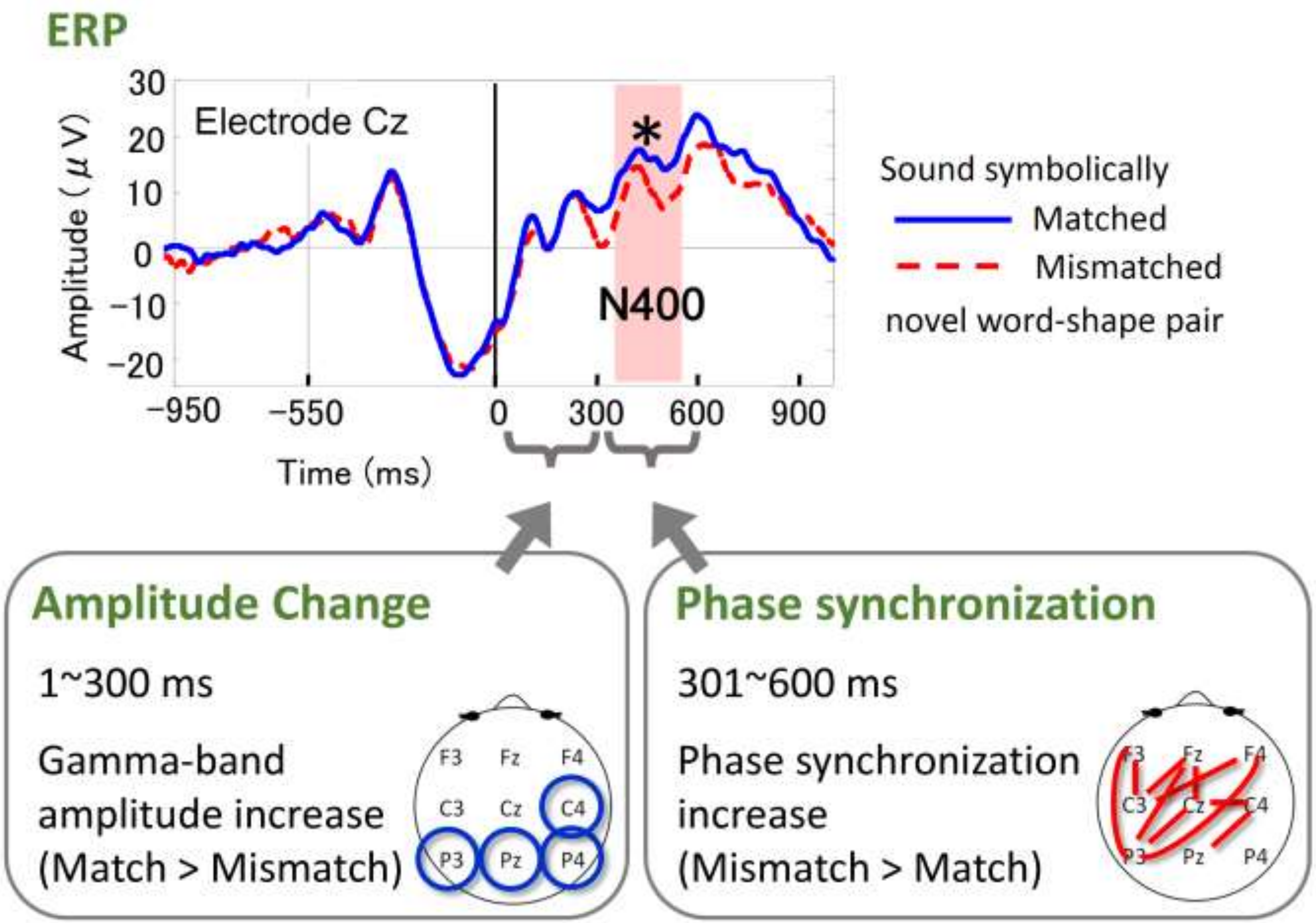
Protocol

Task:
Participants watched and listened to the stimulus *passively*.



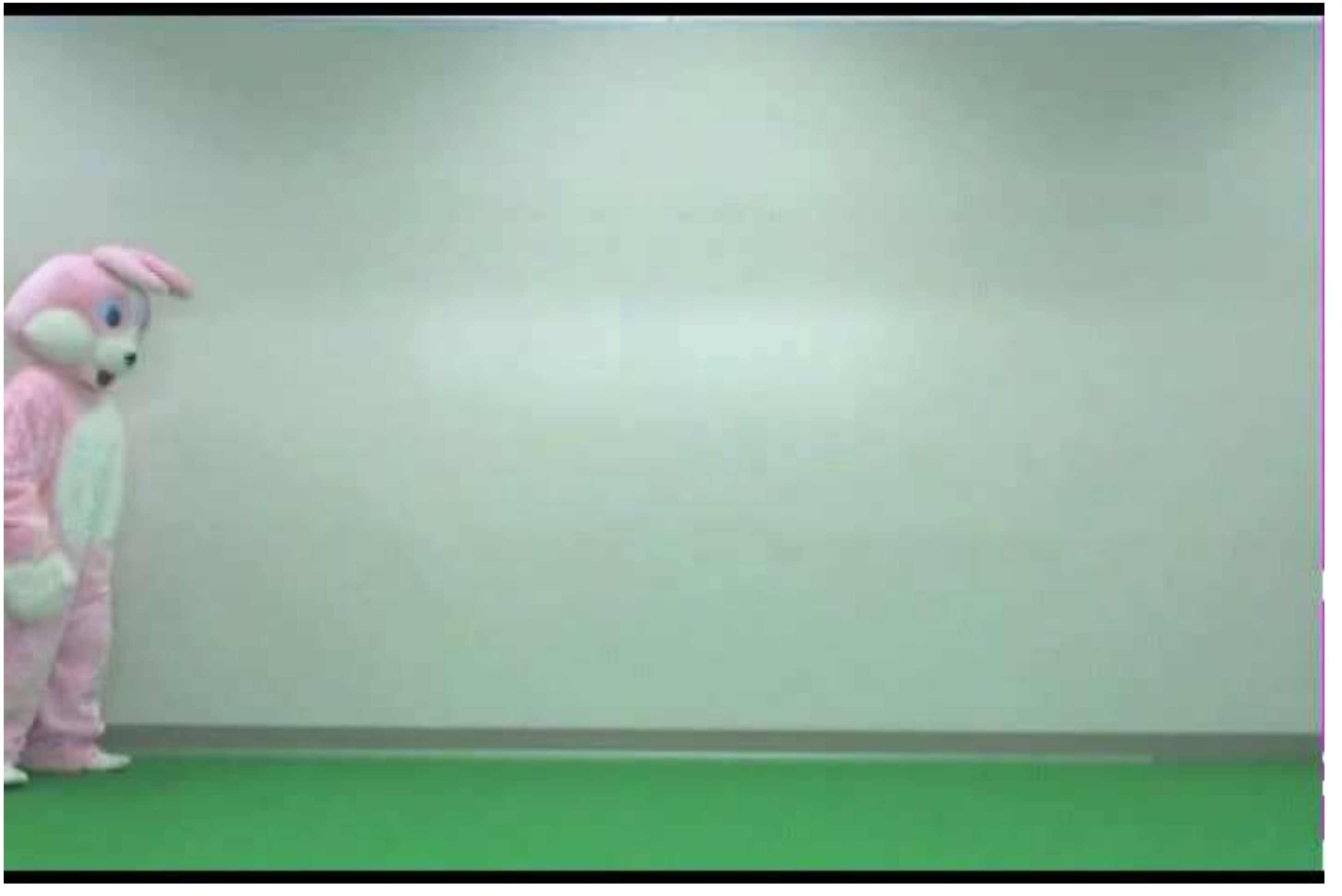


ERP, Amplitude Change, Phase synchronization

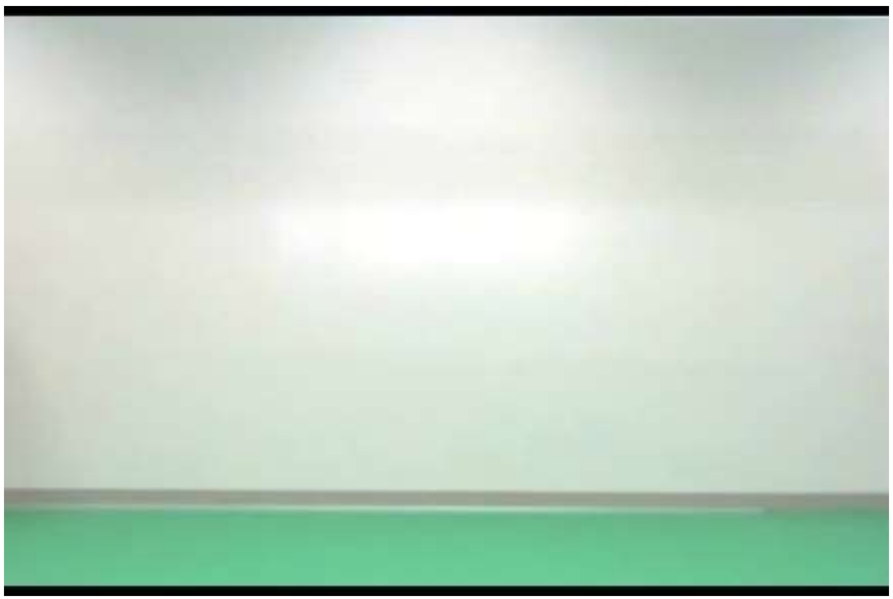


Asano et al.,in press *Cortex*

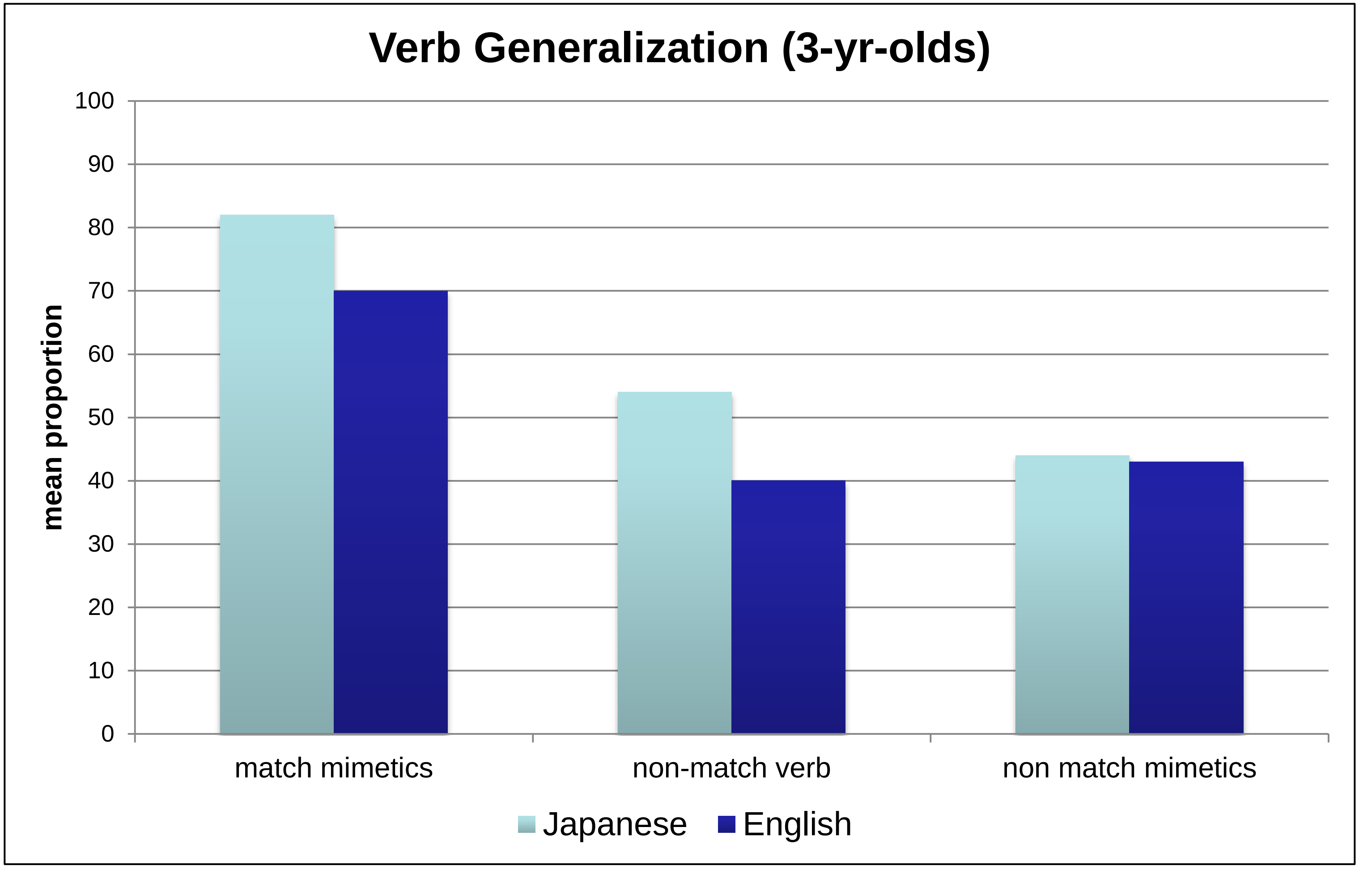
SS helps Novel verb generalization



Imai et al., 2008, Kantartzis et al., 2011



Sound symbolism helps novel verb generalization in Japanese and English children



Imai et al.,2008, Kantartzis, 2011

- Sound symbolism scaffolds infants to break into the abstract system of symbols
- Sound symbolism continue to help young children, through toddlerhood, in their dealing with the Quinian problem

Problem 2
What cognitive function makes language learning possible

Children need to infer the meanings of words on their own

- Sound symbolism or other iconic scaffolding may not be available all the time
- Simple trial and error does not work
- They have to make a series of inferences to narrow down the meaning of new words

Children need to infer the meanings of words on their own

- Ex.) Word learning situation:

This is an apple.

Which is an apple?

A: Object

Teaching:
taught relation

B: Symbol

apple

**Producing:
untaught relation**

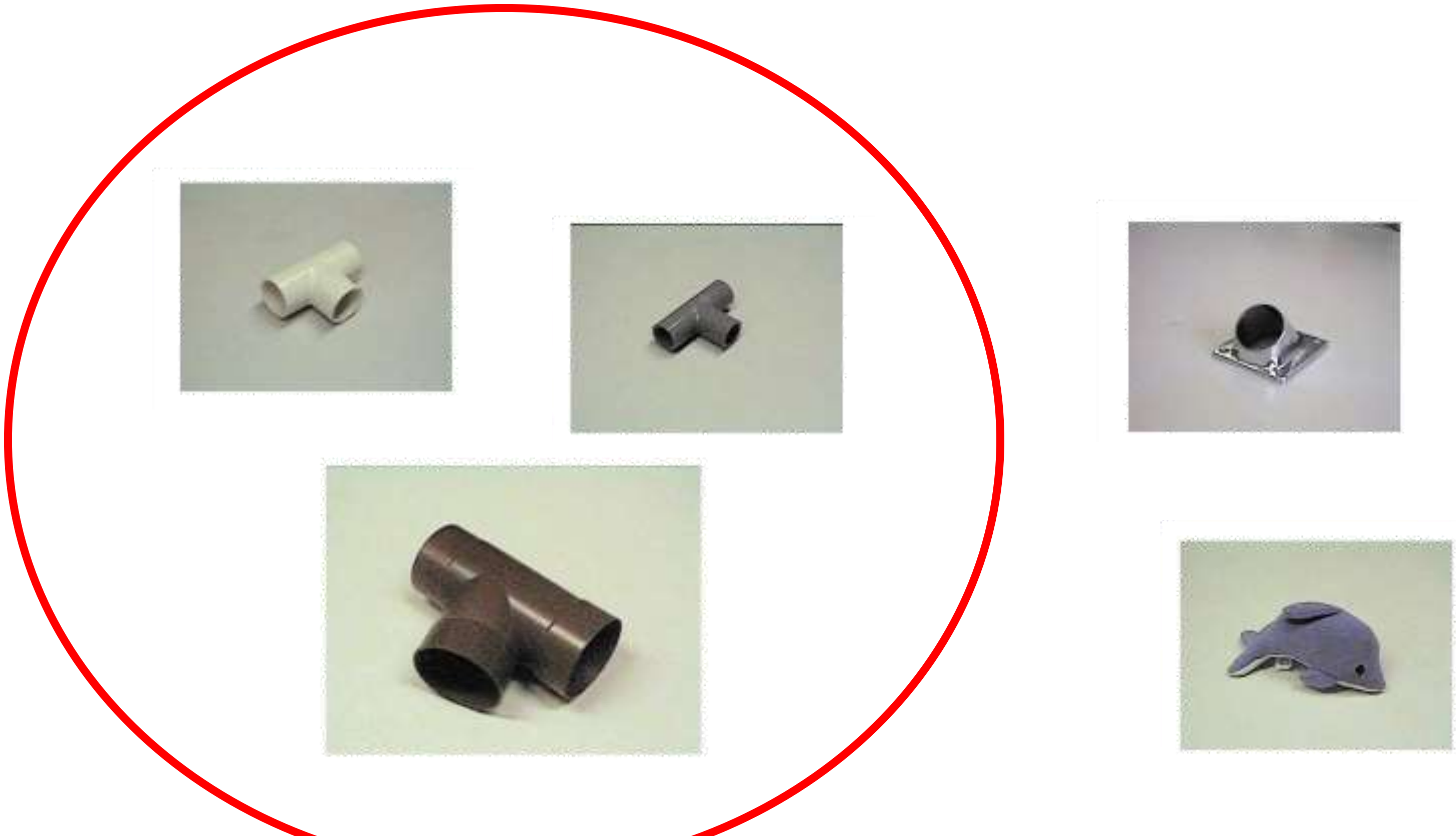
Contingency between sounds and referents is symmetrical

Non-human animals do not do symmetrical reasoning

Kore wa dakkusu desu

This is Dax (Proper name)/ some dax (material)/ dax (property)/ a dax

Imai & Haryu, 2001



They do not think that the label is a proper name.

Shape is important, but **color** and **material** are not.

Test with unknown substances

Top: Wood shavings
Bottom left: Wood shavings   *Bottom right:* small pieces of leather

Imai & Gentner, 1997, Cognition

Inference of a novel word in relation to an already learned word

Learning a new word sometimes changes the boundary of an old word

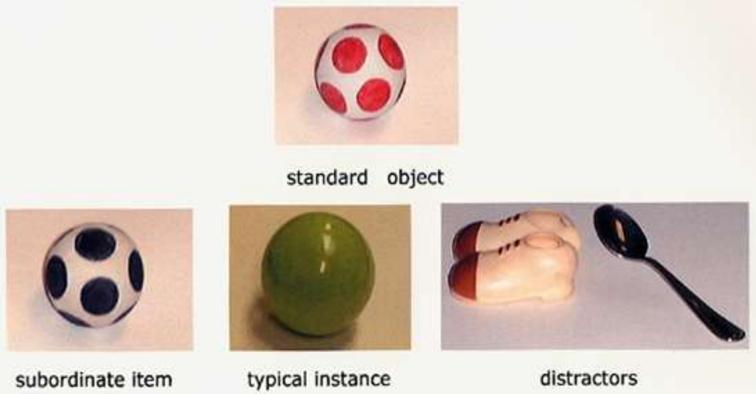


Figure a A sample of stimulus materials

(Ball-set used in the High Shape Similarity condition in Study 2)

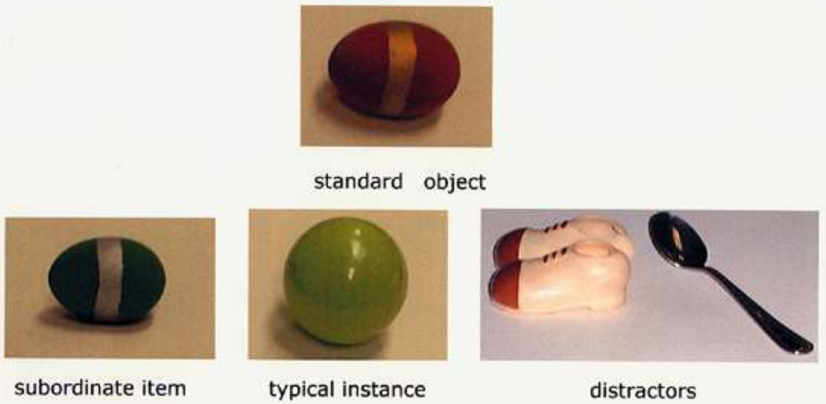


Figure b A sample of stimulus materials

(Ball-set used in the Low Shape Similarity condition in Studies 2 & 3)

Haryu & Imai, 2002, Child Development

Haryu & Imai, 2002, Child Developmen

Word meaning inferences require abduction

- Children need to come up with the most plausible meaning of a new word using knowledge they have
  - Meta-knowledge about mappings between grammatical class and meanings
  - Meta-knowledge about patterns of generalization
  - Knowledge about known words

All of the inferences are heuristic reasoning

- Simplest heuristic reasoning

⇒symmetry reasoning

Symmetry reasoning is behind

- Causal reasoning
  - When someone did X, then Y happened.
  - Y happened, therefore someone MUST HAVE done X.
- Confusion of necessary and sufficient conditions
  - Teacher : To get a course credit, you have to come to the class 80% of the class meetings.
  - Students: I was in the class 90% of the time, therefore I should be able to get a course credit.

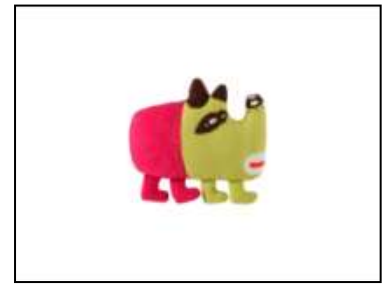
Is the symmetry reasoning species specific and innate cognitive function?

- Do infants possess a symmetrical reasoning bias BEFORE learning words?
- Does the bias arise AS A CONSEQUENCE of word learning?

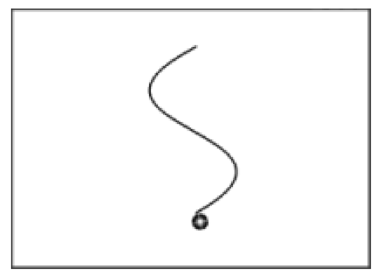
Tested 8-month-olds

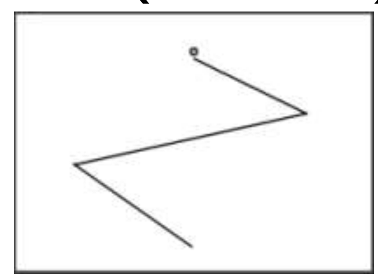
- Participants
  - 8- month-olds
- Stimuli
  - Toy（A1, A2）
  - Ball movement
    - B1(↓),B2(↑)
- Paradigm
  - Habituation switch

Toy (A1, A2)



Ball movement (B1, B2)



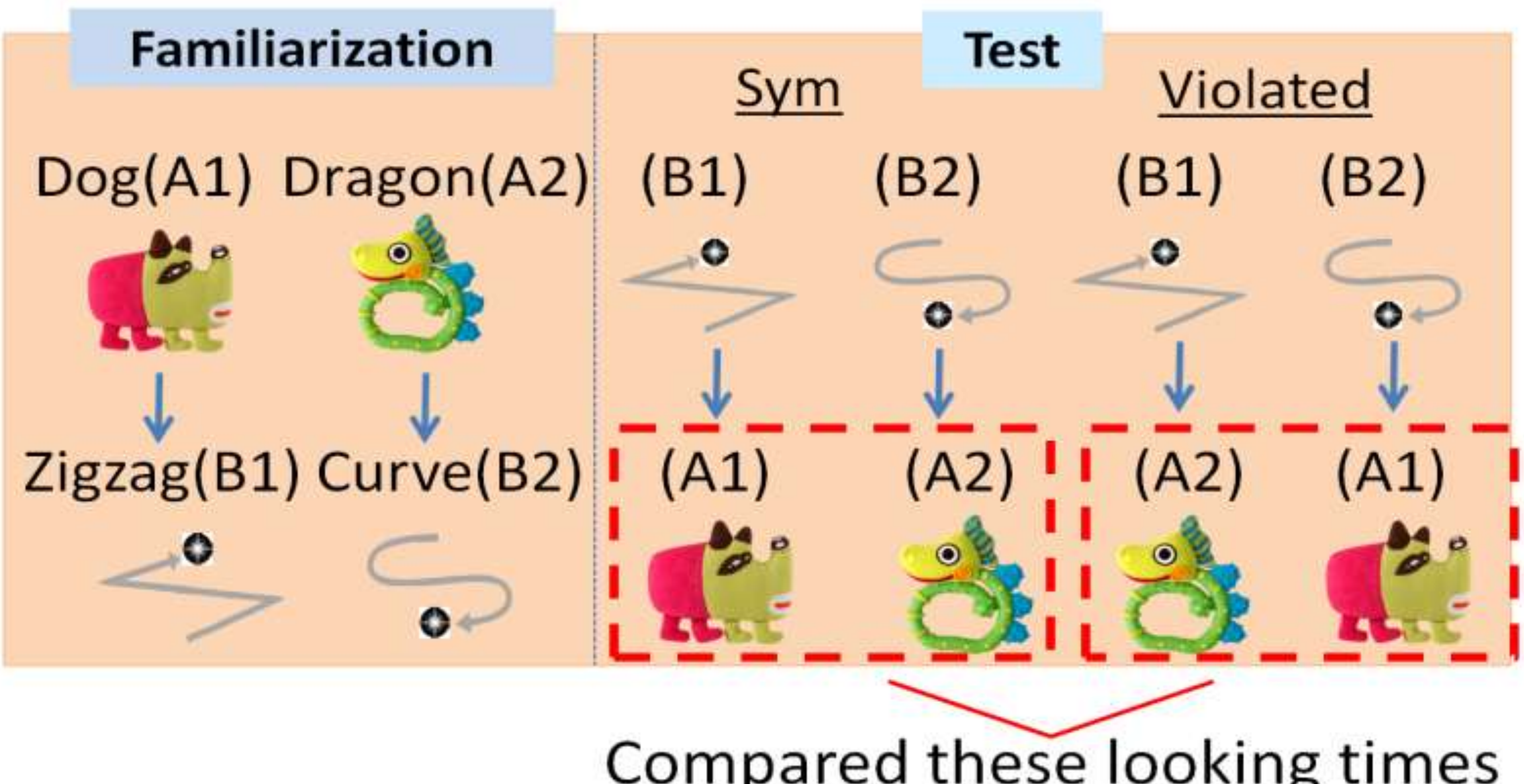


General method

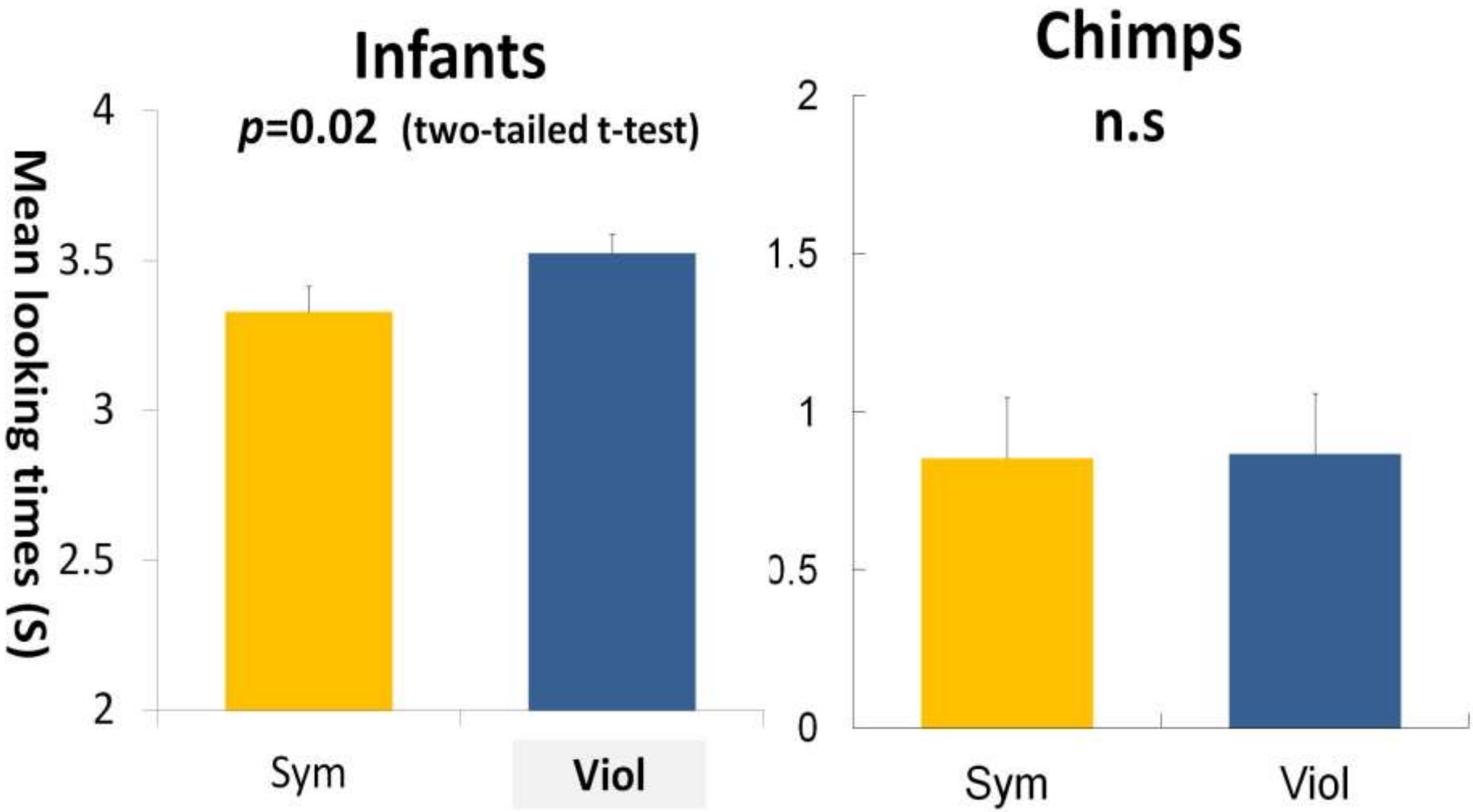
Training: Infants were habituated with A→B Contingency

Test: Direction of the contingency reversed.

Question: Do infants and chimps think that the violation of the combination anomalous when the contingency was reversed?

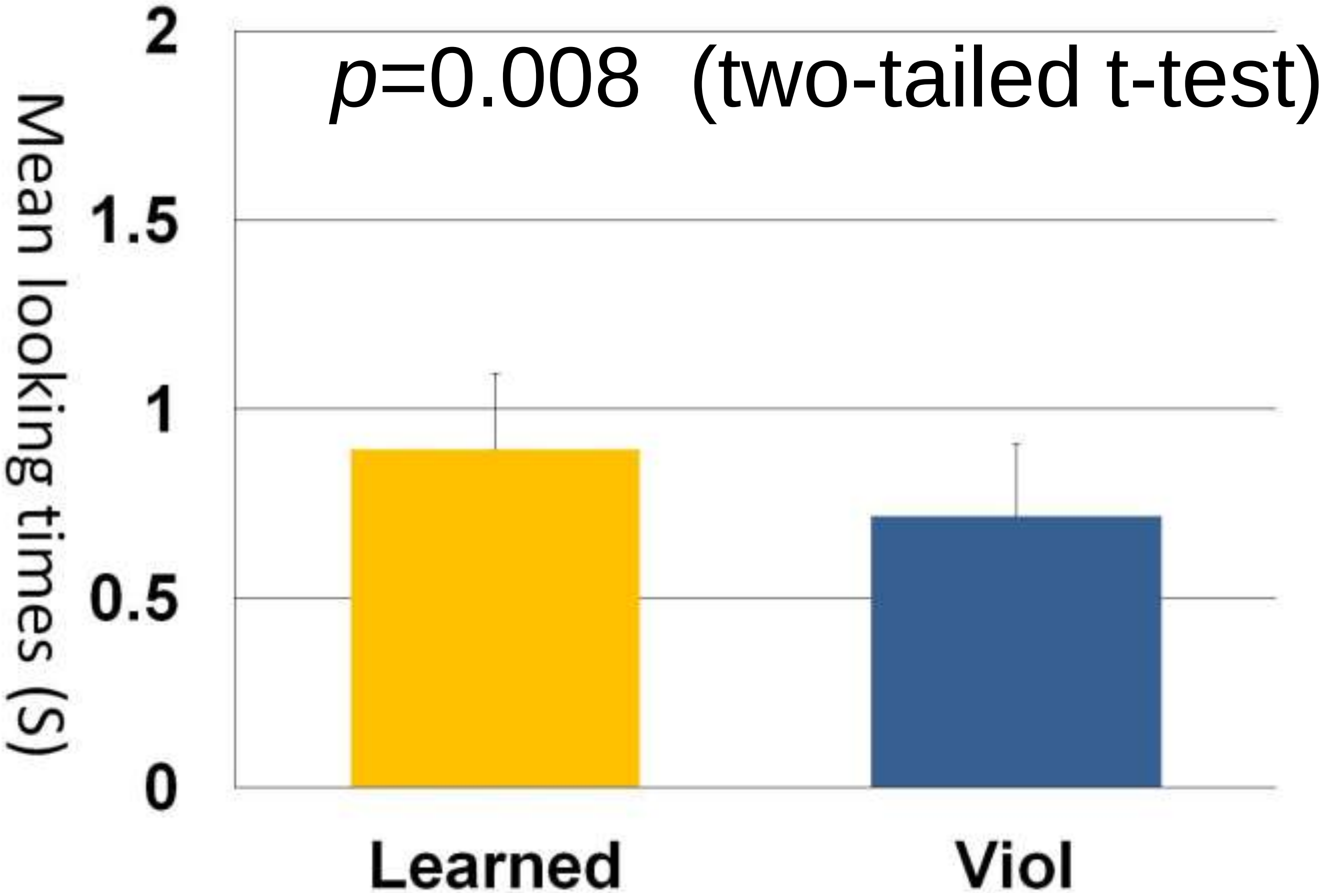


Symmetry condition



Only human infants detected the violation

Chimps did learn the contingency when the temporal direction is not reserved



7/7chimps showed significant preferences (p = 0.0078, binomial test)

Symmetry reasoning as a prerequisite of language learning?

- Human infants do symmetry reasoning, which is a non-logical heuristic reasoning, but chimpanzees do not.
- Symmetry reasoning is human-specific cognitive function, and may be a critical prerequisite of language learning and other uniquely human flexible heuristic thinking

Problem 3
How do children learn the language-specific semantic system





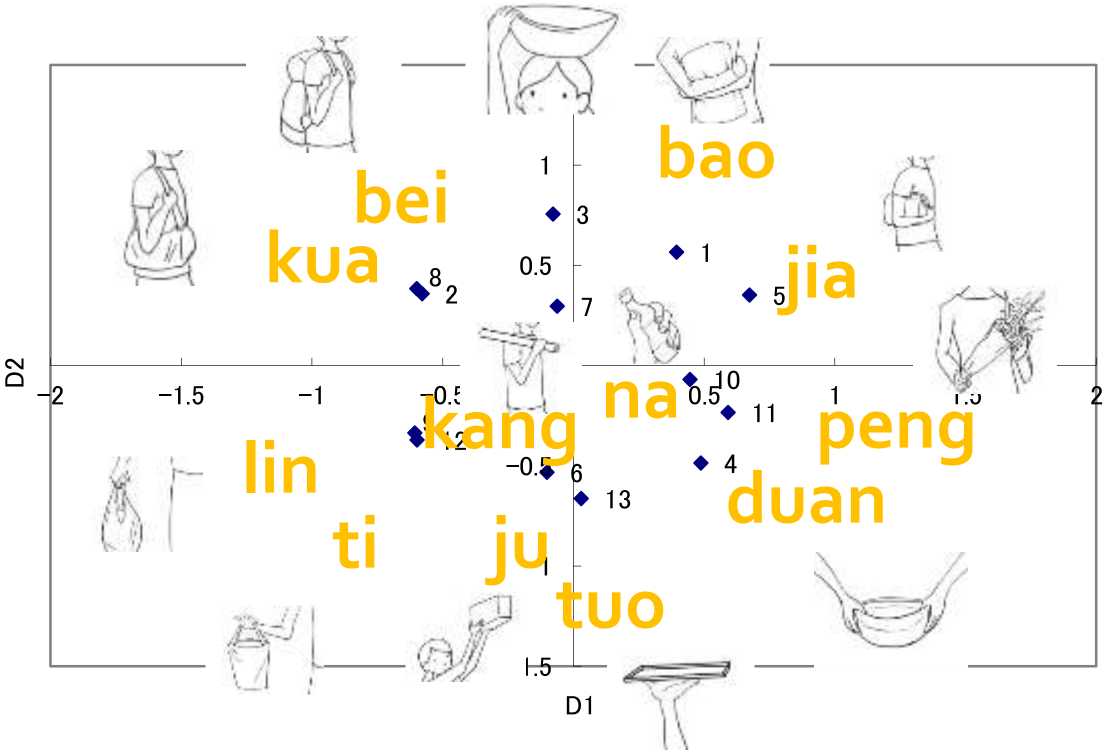








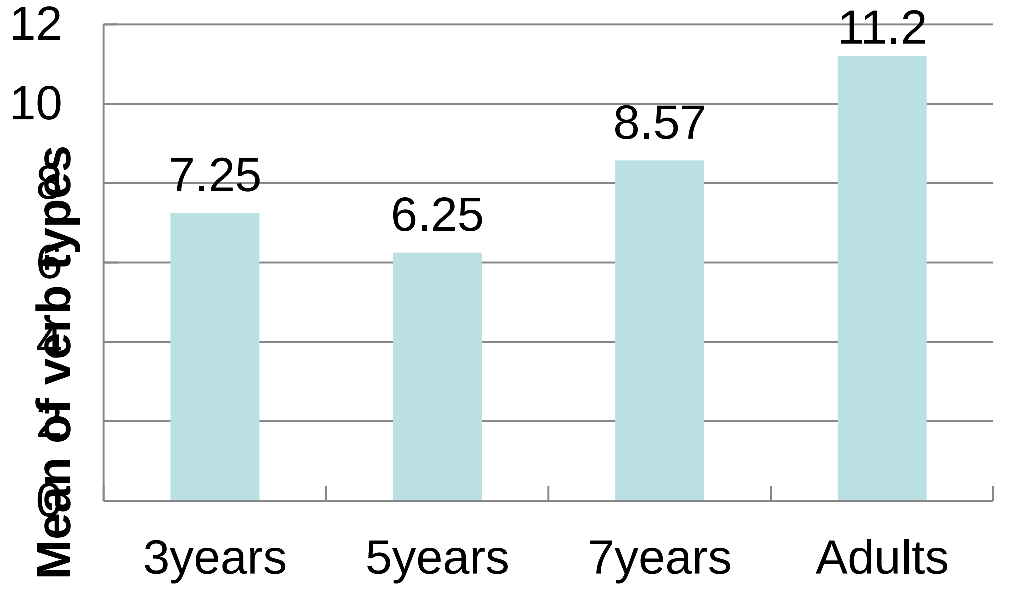
How Chinese-speaking adults use these verbs



Saji et al., 2011, Cognition

How many verbs did children produce?

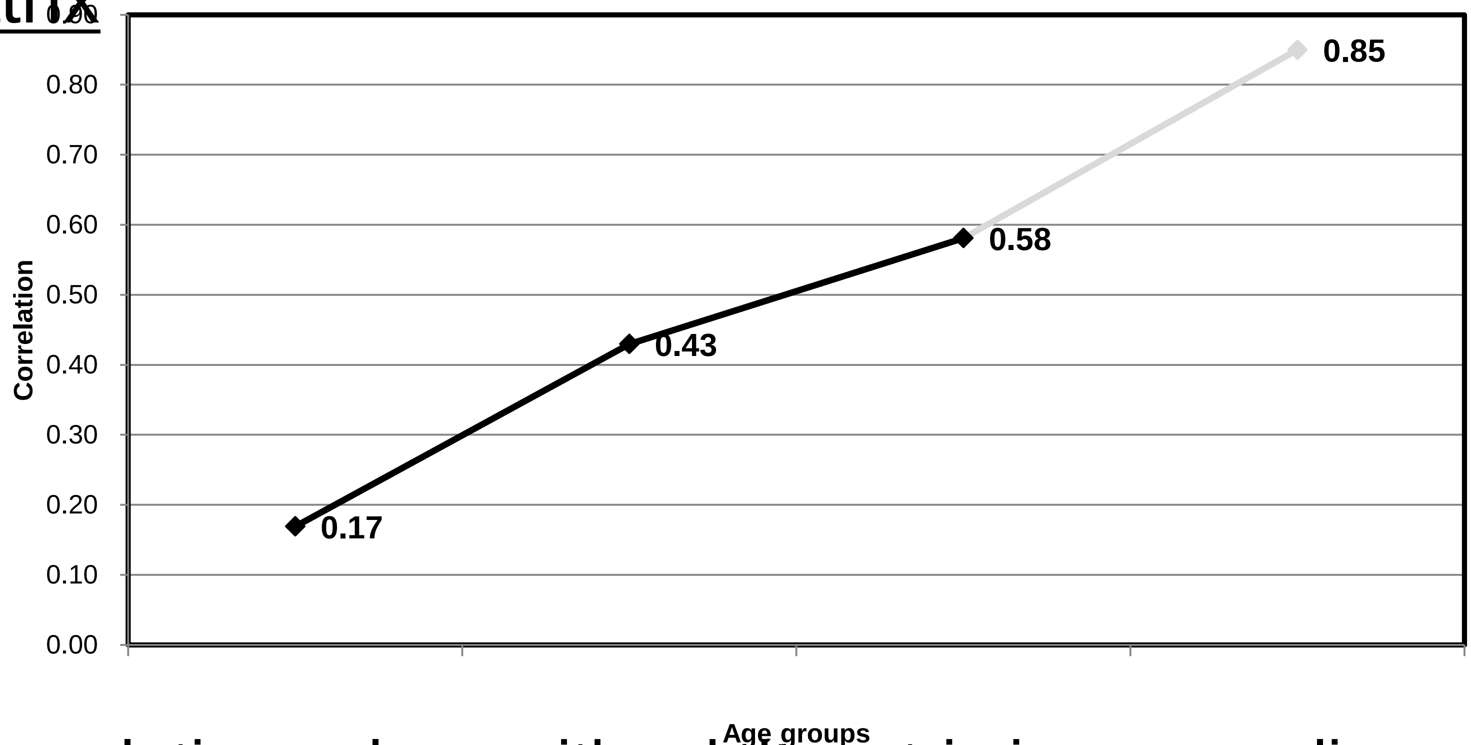
Number of verbs produced for 13 videos



- No difference among the three age groups in children

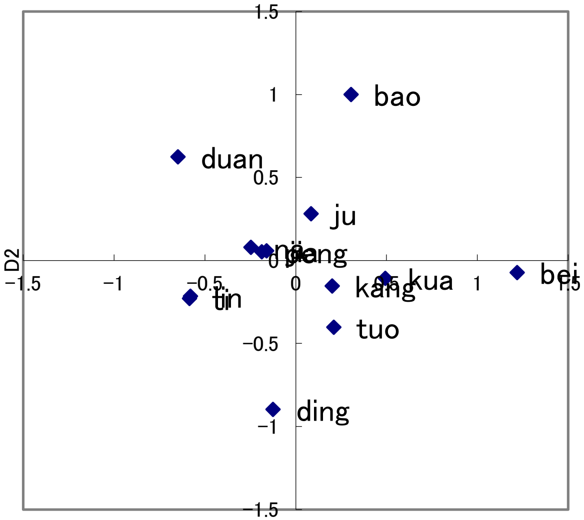
When and how does production of children converge into that of adults'?

Correlation between children's matrices & adult matrix

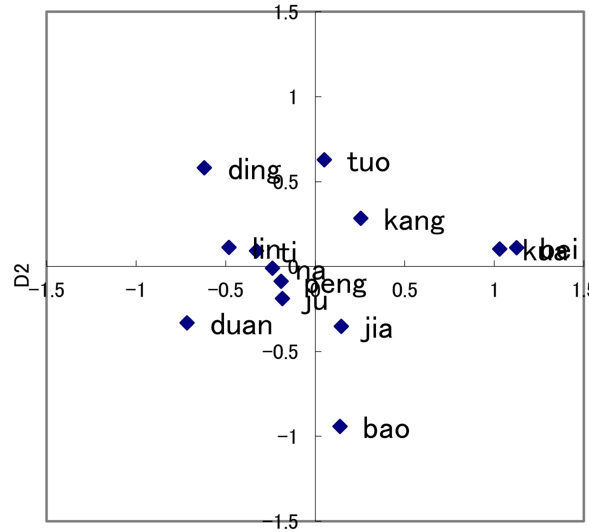


- Correlation values with adult matrix increases linearly.
- But even in 7years, correlation value is not so high.

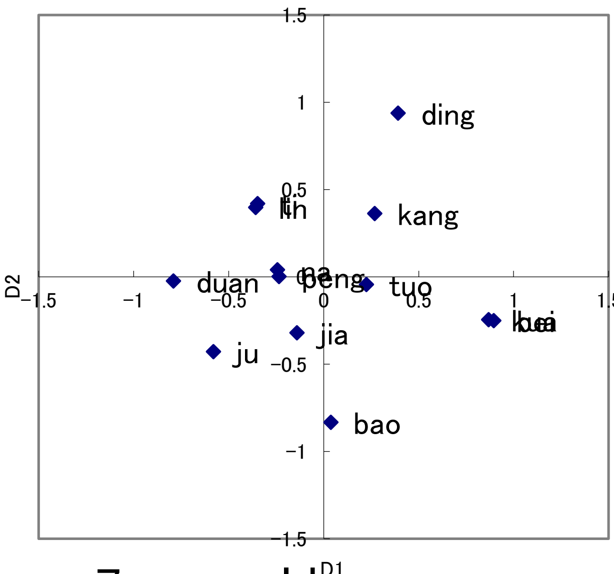
MDS configurations for each age group



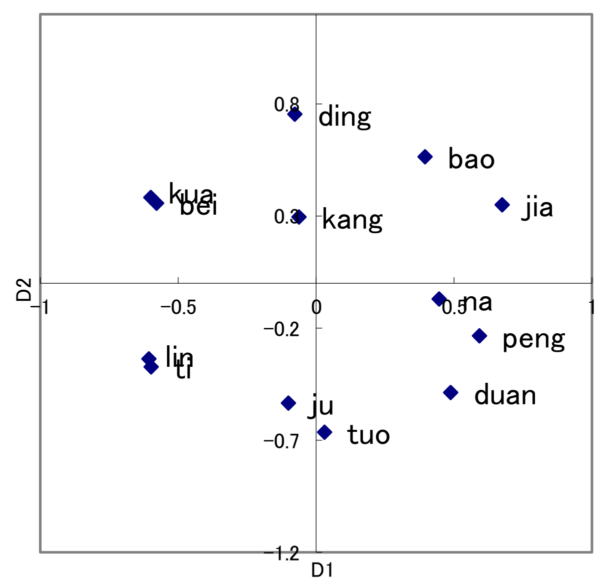
3years-old



5years-old



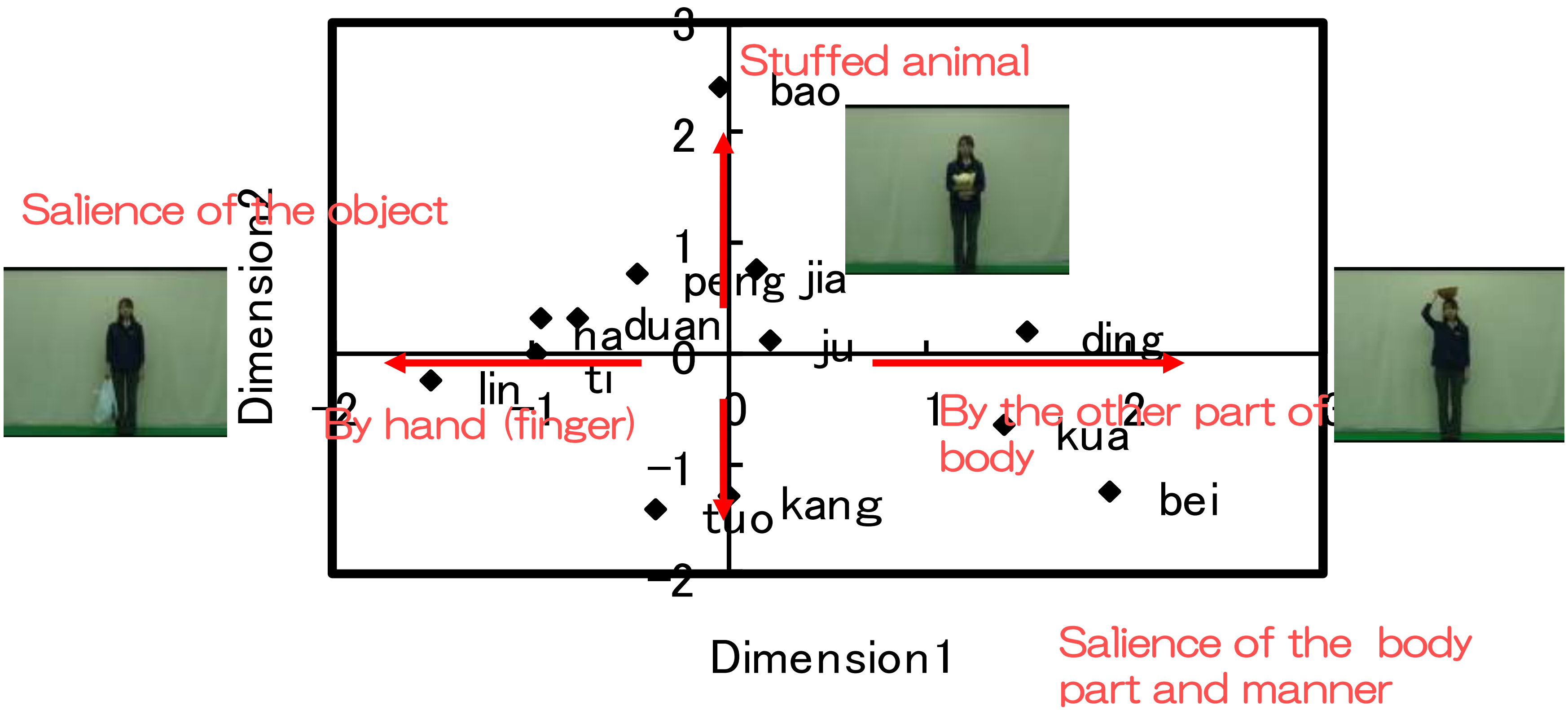
7years-old



Adults

INDSCAL Analysis

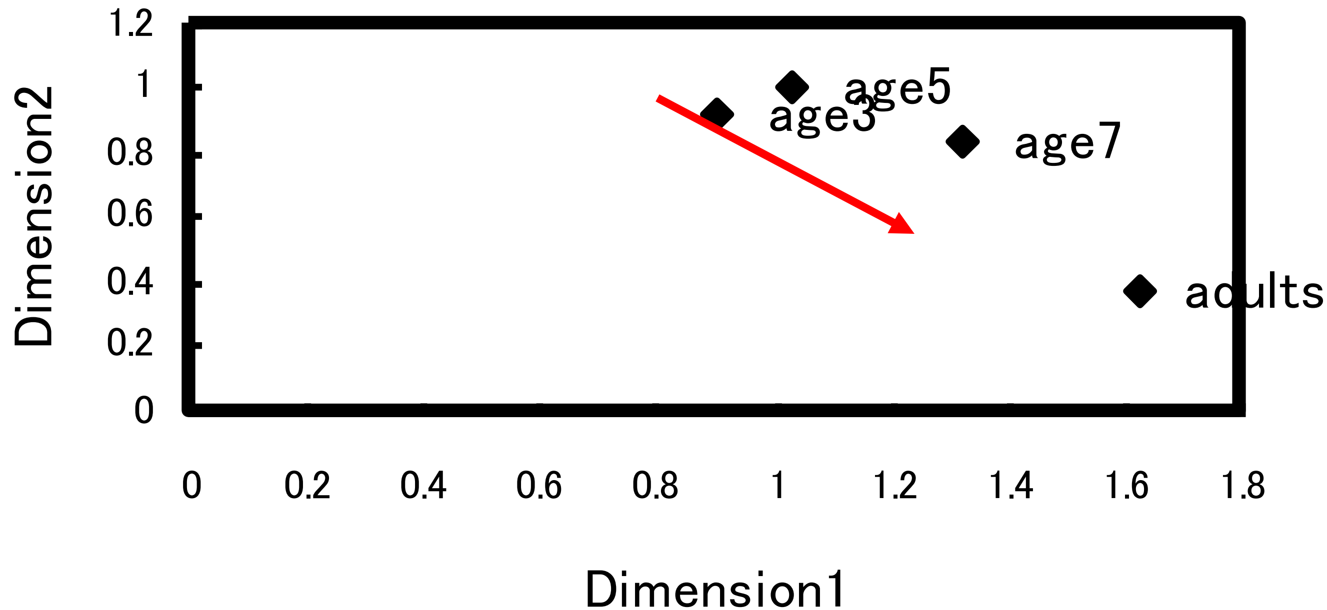
- INDSCALによる検討(1)
  - Common Space(D1XD2)



S:0.21(D2)->0.14(D3)

MDS & INDSCAL analysis

- <u>Results：</u>Individual space



Shift of the basis of generalization
Reliance of the objects → Reliance of manner

How to build a system without a blue print of the end state of the lexicon

- Children learn the elements (individual words) and the system in parallel and both are continuously updated.
- The trick is to create the rough map of the system fast, and keep refining the system and individual elements gradually and slowly.
- Ability to use multi-modal information and ability to make heuristic (abductive) reasoning play key roles there.