Synaesthesia: A New Perspective for Understanding the Development of Perception and Even Language

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McMaster University

Synaesthesia

Greek: *syn* (union) + *aesthis* (sensation)

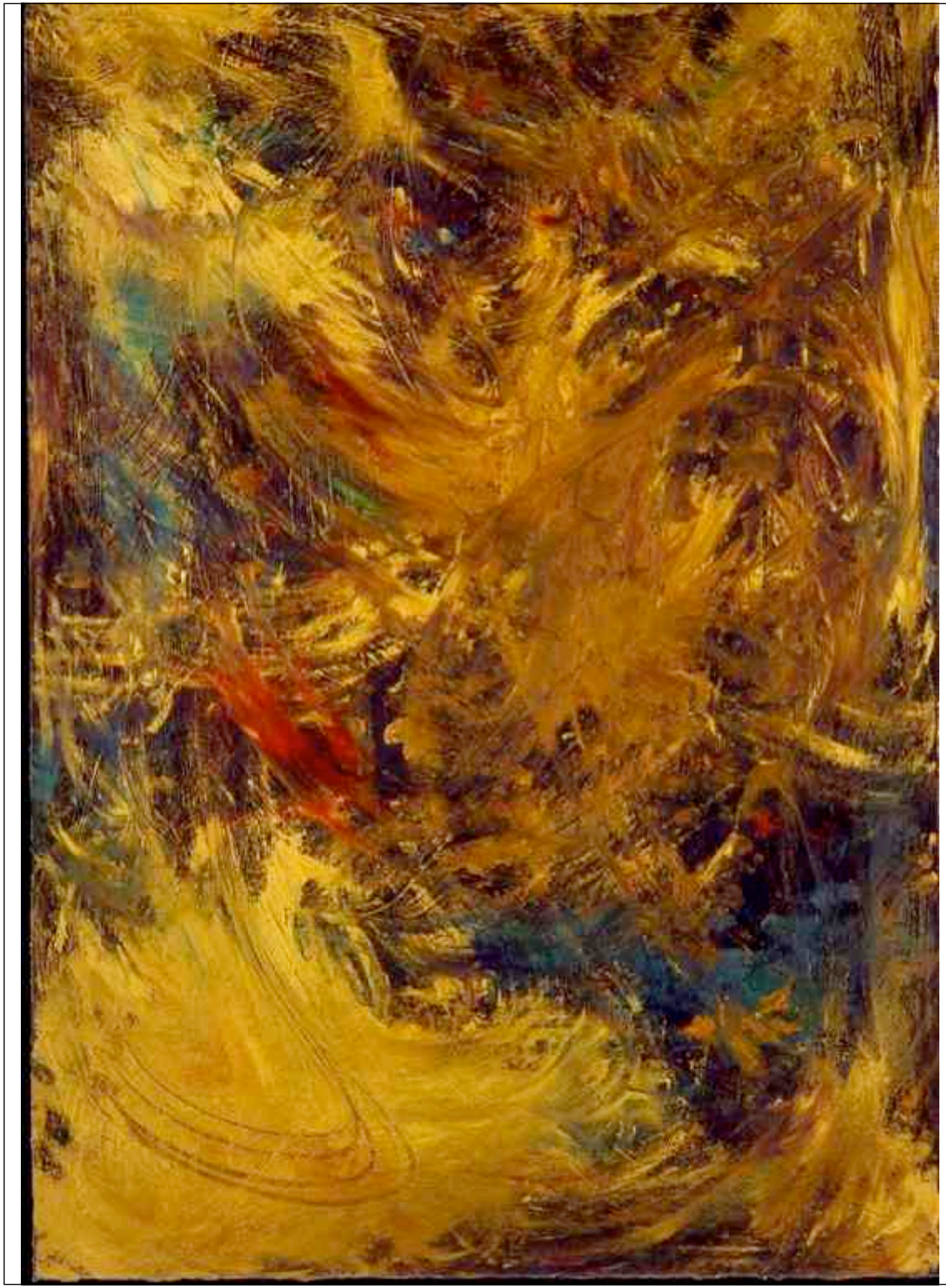
Synaesthesia: ~54 types

Sound of C# on a flute

$\Rightarrow$ 

$\Rightarrow$ 

$\Rightarrow$ *taste of oranges not quite ripe*



Coloured Hearing

...while I listened to Santana's version of a song called Adouma. ...I played this song over and over again as I painted the moving colours.

Runs Off In Front,Gold

Oil on paper, 105 x 70 cm

Carol Steen 2003

Synaesthesia: ~54 types

Coloured letters and digits

2 W ⟹ 

5 P ⟹ 

4 H ⟹ 

Coloured letters and digits

Adapted from Pat Duffy,
Blue Cats and Chartruese Kittens

Synaesthesia

Sound of a trumpet

$\Rightarrow$ 

$\Rightarrow$ 

$\Rightarrow$ *taste of oranges not quite ripe*

- Automatic
- “All their lives”
- Mappings are consistent over years.
- Runs in families

Runs in families

4-year-old

A B C D E F G H I J

A B C D E F G H I J

A B C D E F G H I J

1 2 3 4 5 6 7 8 9

1 2 3 4 5 6 7 8 9

1 2 3 4 5 6 7 8 9

Her mother

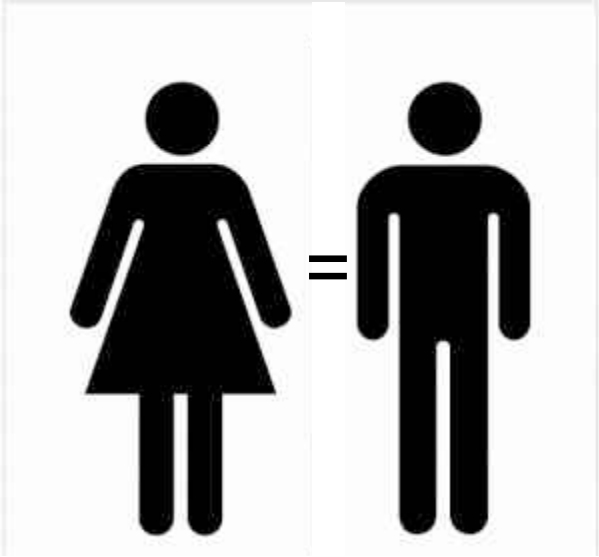
A B C D E F G H I J

1 2 3 4 5 6 7 8 9

Spector & Maurer, 2009

Synaesthesia: Incidence

4% - 5%



Simner et al., 2006
Day, 2008

Synaesthesia:

Stroop effect

If

2 induces

5 induces

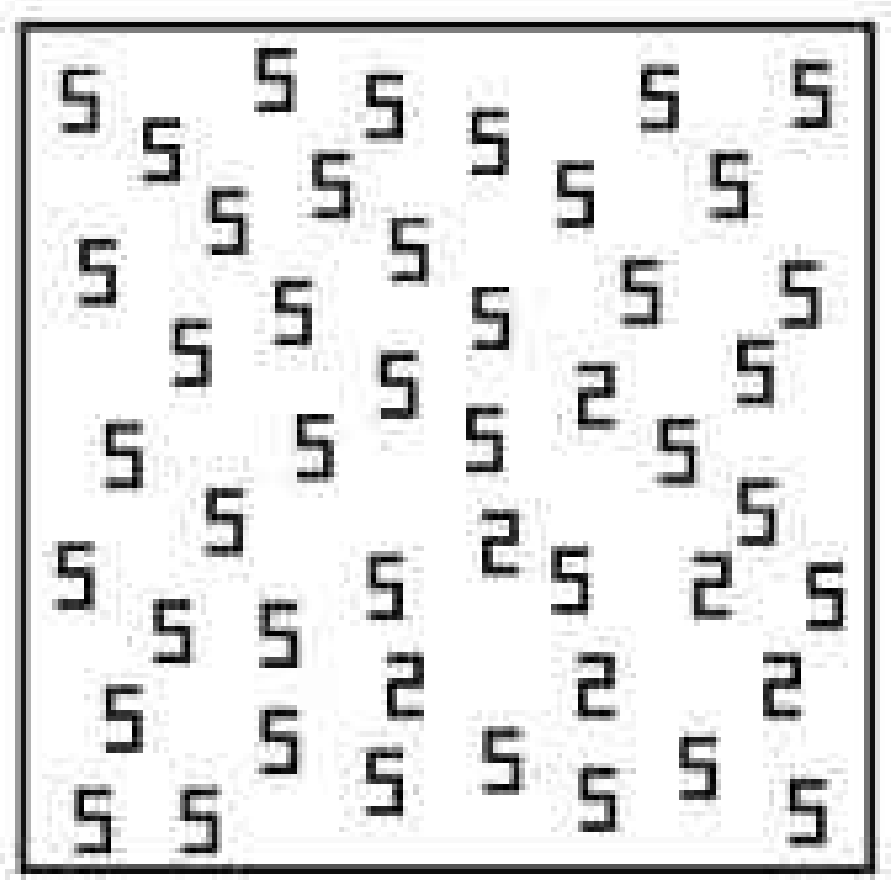
2 5 2 5 | 5 2 2 5

Easy | Hard

Dixon et al. 2000
Mattingley et al. 2001
Mills et al. 2002
Myles et al. 2003
Palermi et al. 2002

Synaesthesia:

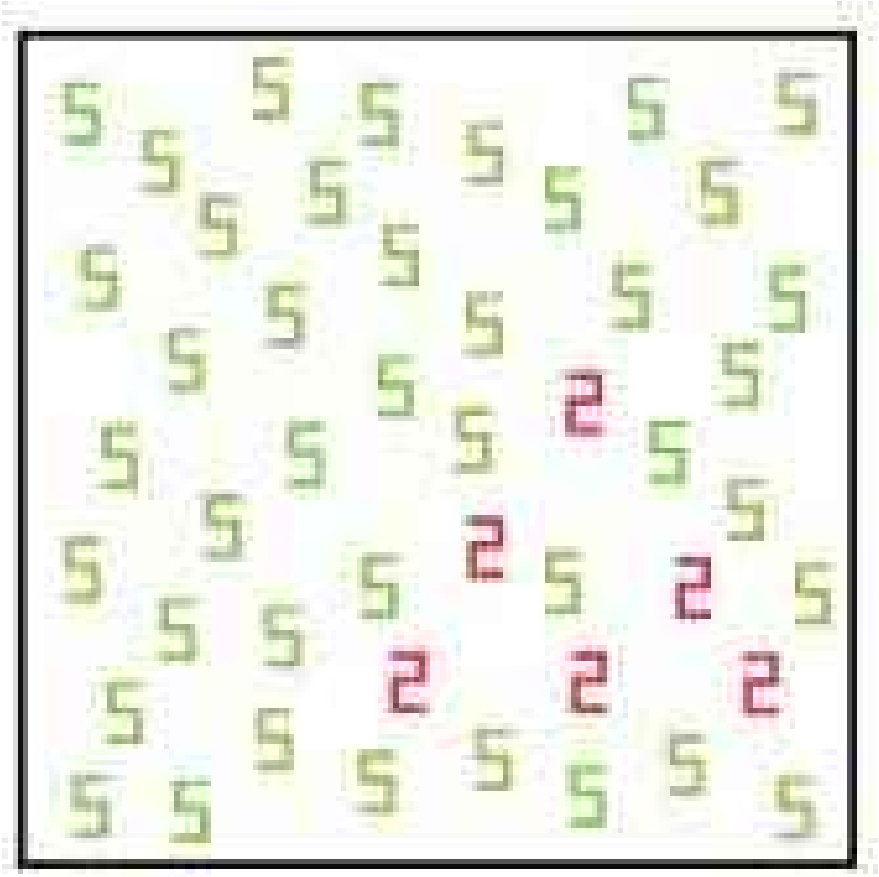
Pop-out



Ramachandran & Hubbard, 2001
Laeng et al. 2004
Palermi et al., 2002
Smilek et al. 2003
Hubbard et al., 2005

Synaesthesia:

Pop-out

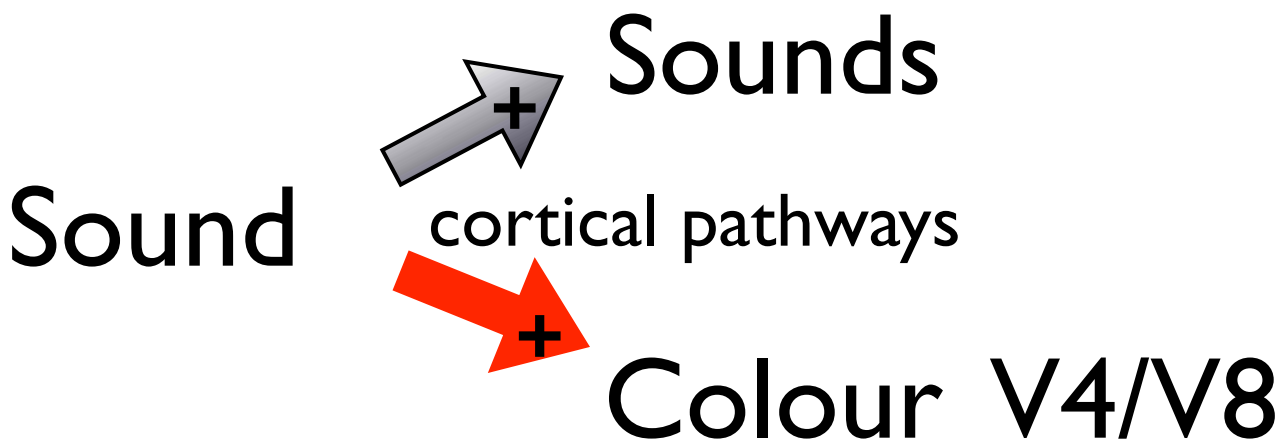


Ramachandran & Hubbard, 2001
Laeng et al. 2004
Palermi et al., 2002
Smilek et al. 2003
Hubbard et al., 2005

Synaesthesia:
works like typical perception

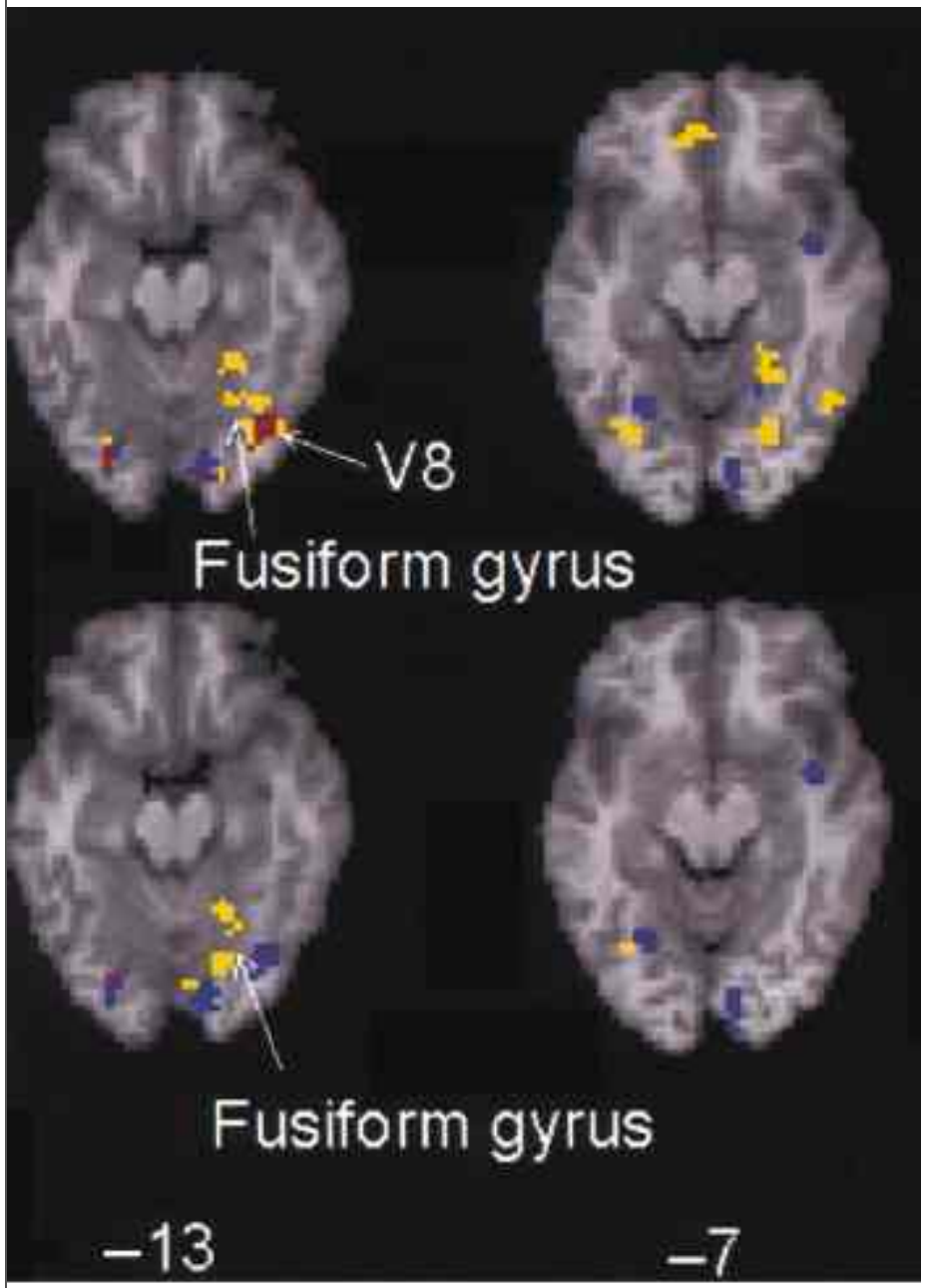
- Same patterns of interference & facilitation
- Same brain areas

Coloured hearing



Gray et al. 1997
Nunn et al., 2002
Paulesu et al., 1995
Aleman et al., 2001

Coloured hearing



Synasethete

Control

Word-tone

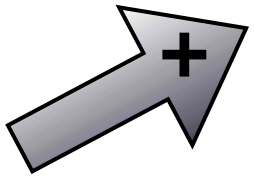
Colour

Both

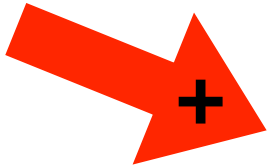
Nunn et al., 2002

Coloured graphemes:
seeing letters in colour

Letters



Letters cortical pathways

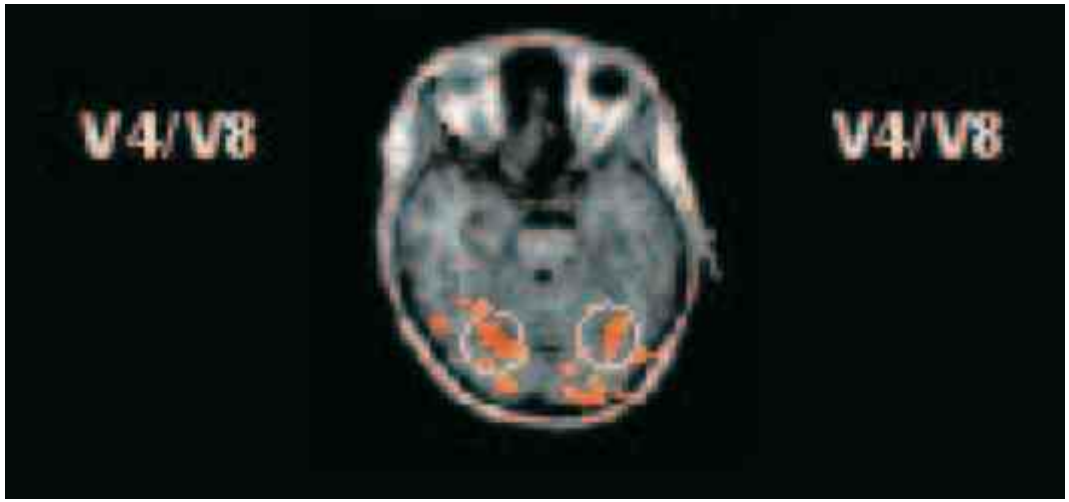


Colour V4

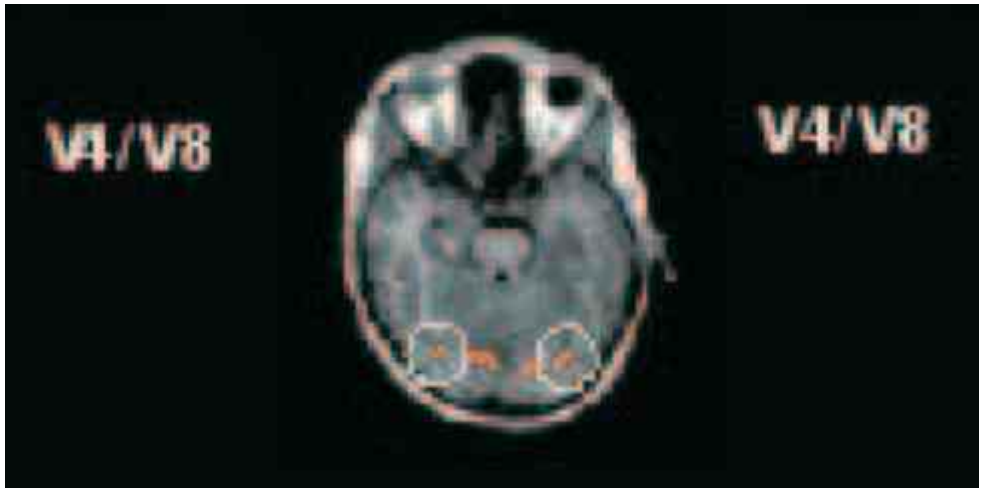
Binding colour to shape

Hubbard et al., 2005
Sperling et al., 2006
Esterman et al., 2006

Coloured graphemes: seeing letters in colour



Colour



Black letters

Sperling et al., 2006

Synaesthesia:
result of normal developmental process

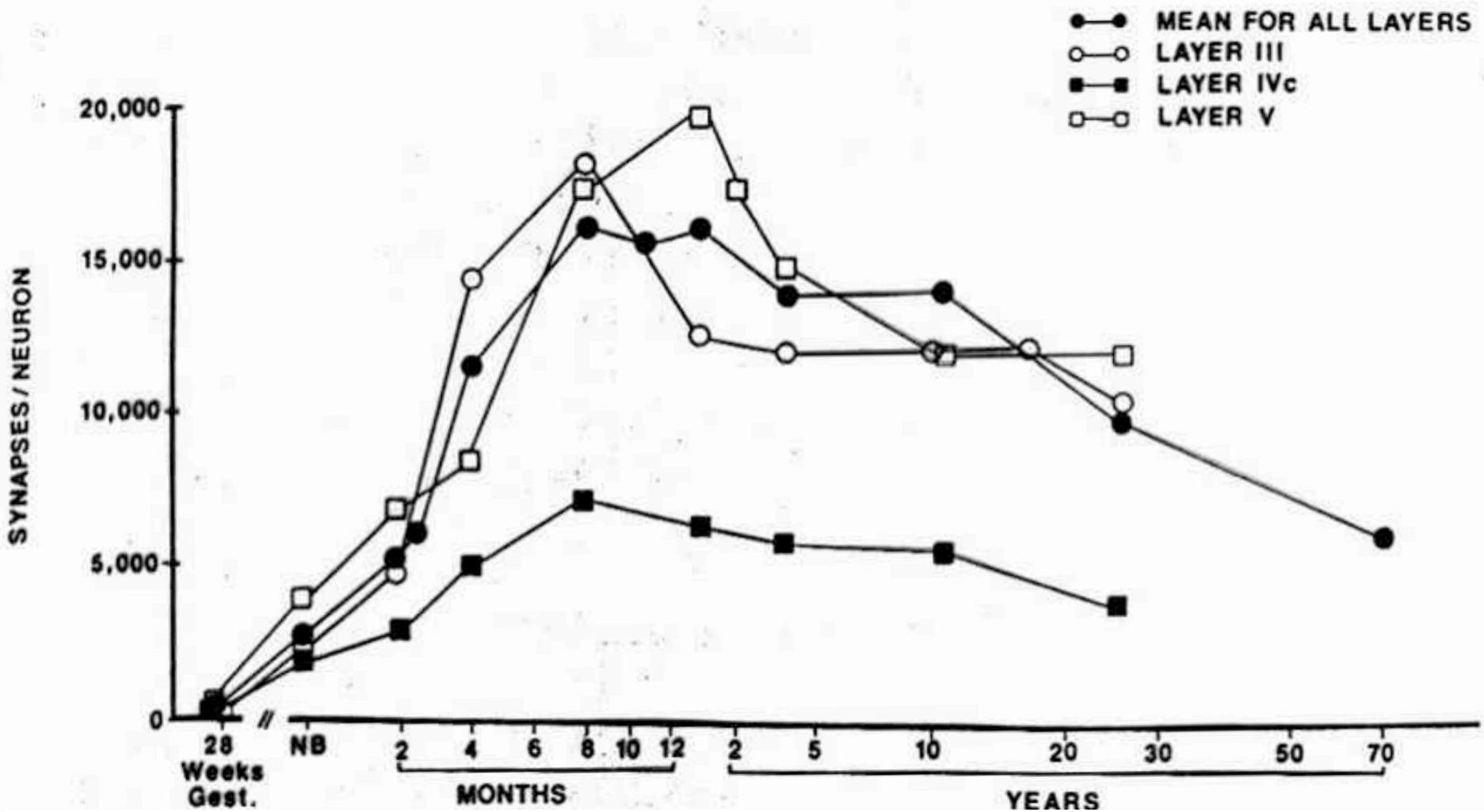
Transient connections between sensory cortices

- Kitten
  - Auditory $\Leftrightarrow$ visual $\Leftrightarrow$ tactile $\Leftrightarrow$ motor cortex
- Infant monkey
  - Auditory cortex $\Rightarrow$ visual cortex V4 (colour)

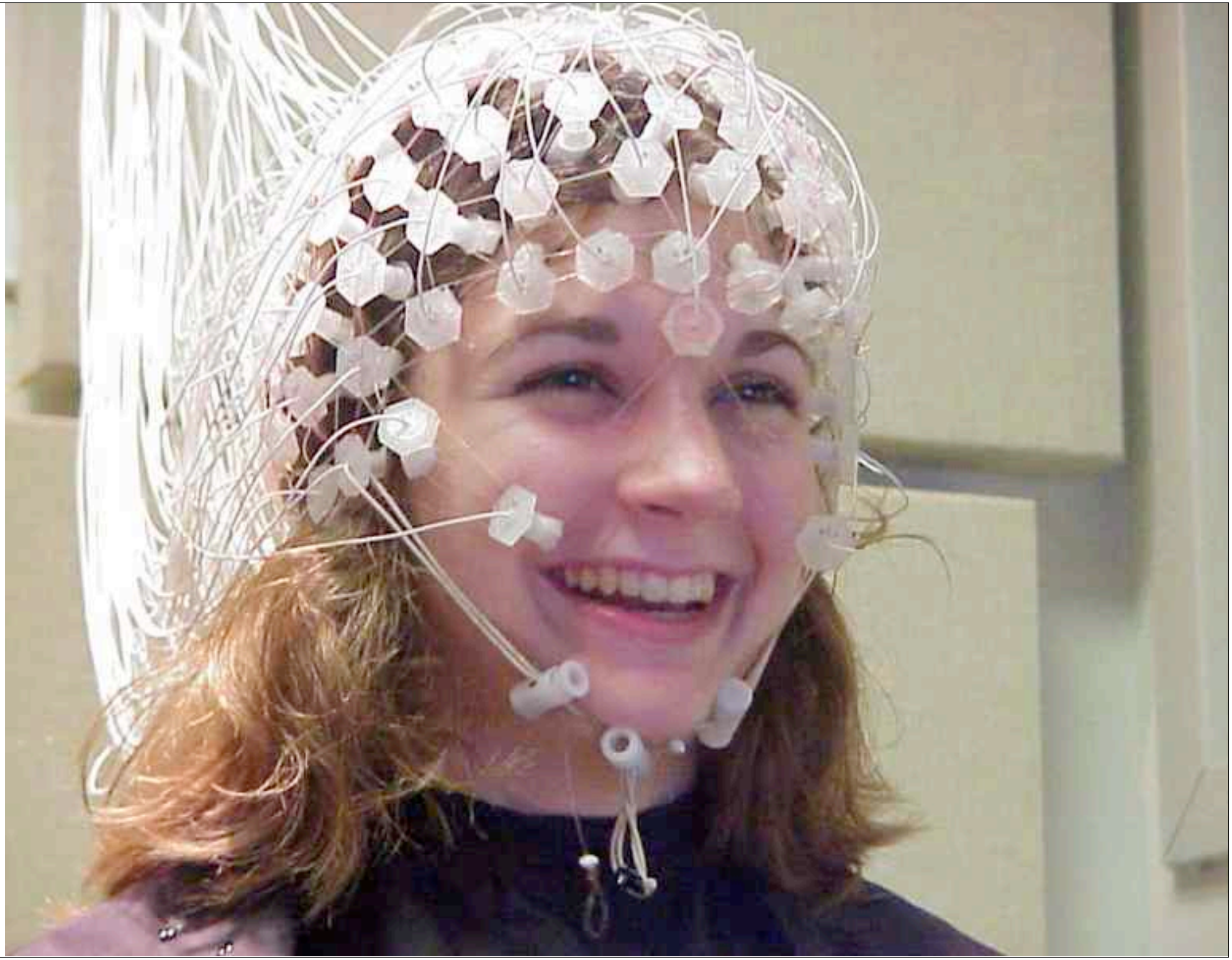
Dehay et al., 1984, 1988

Kennedy *et al*. 1997

Transient connections: Visual cortex



Huttenlocher, 1990



Adults' event-related potentials:

Auditory cortex

Other cortical areas

Neville, 1995

Babies' event-related potentials:

Auditory cortex

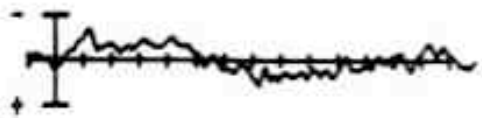
Visual cortex

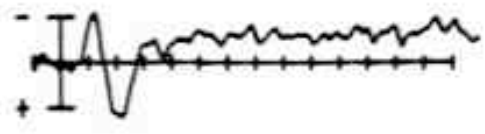
Neville, 1995

Response to Speech

Visual Cortex | Auditory Cortex

Adults





Sound

⇓

Auditory

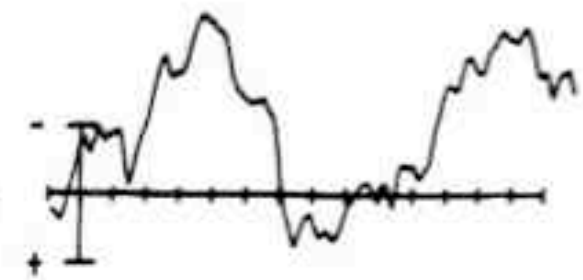
Neville, 1995

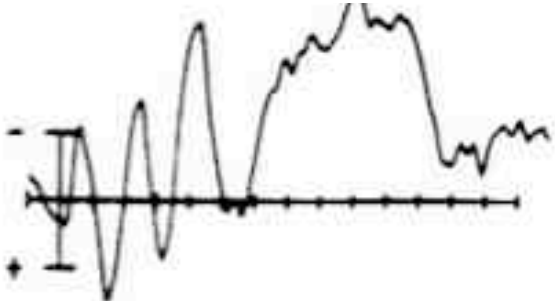
Response to Speech

Visual Cortex

Auditory Cortex

Infants





Sound

⇓

Visual

Sound

⇓

Auditory

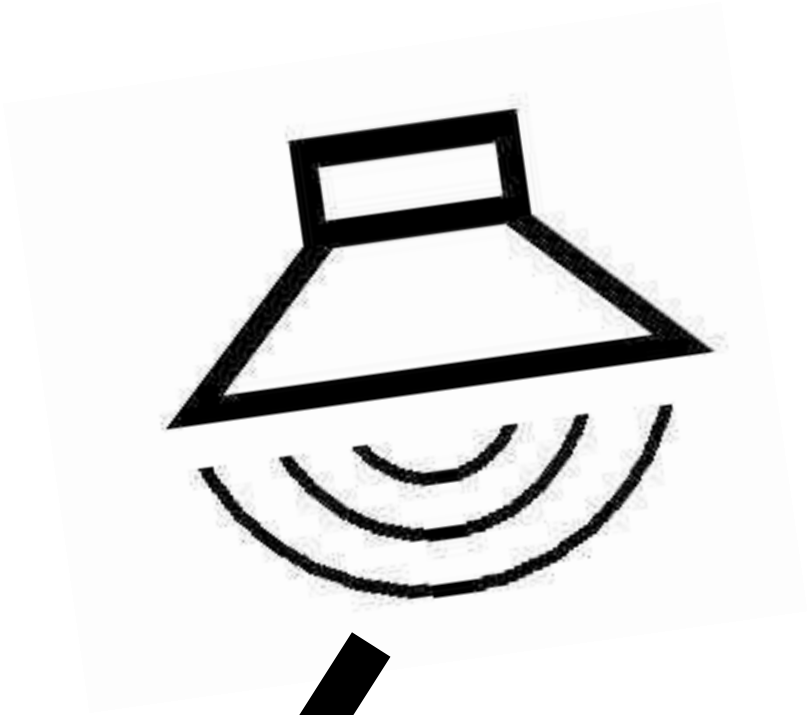
Neville, 1995

Adults' event-related potentials:

Somatosensory cortex

Wolff et al., 1974

Newborns' event-related potentials:



Somatosensory cortex

Wolff et al., 1974

Response to Faces at 2 months

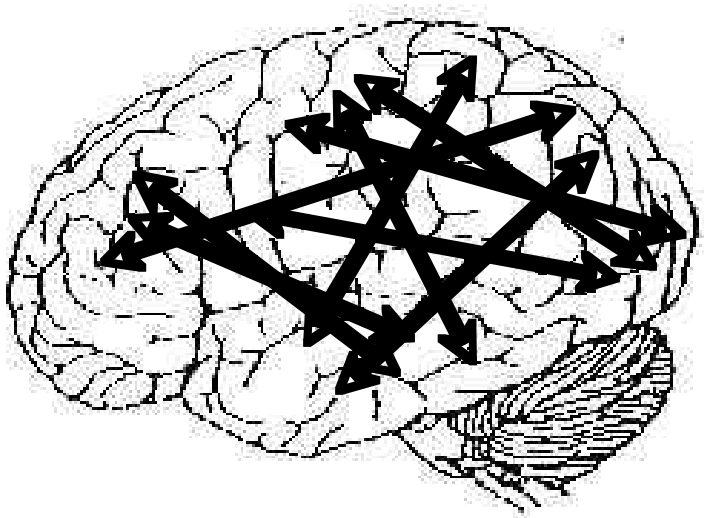
-

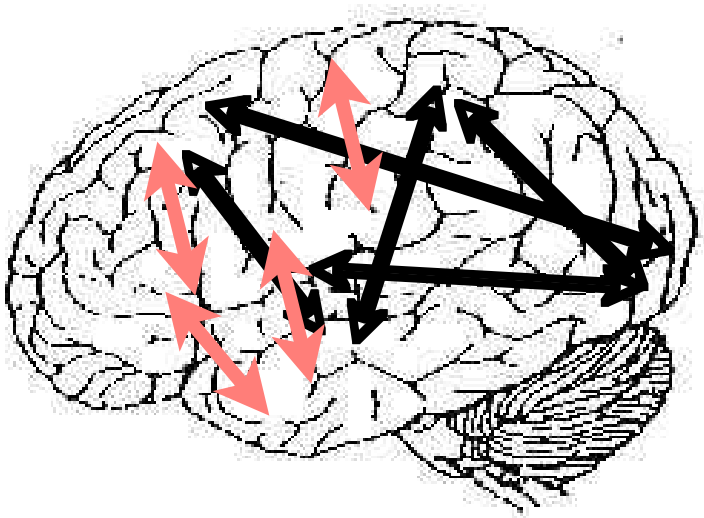
PET

R inferior temporal gyrus (FFA)

L auditory temporal cortex
L Broca's area

Tzaourio-Mazoyer, de Schonen et al. 2002





Early childhood

Synaesthesia

Extra functional connections among cortical areas

Experience prunes connections

→ Visual cortex → Vision
Hearing
Touch
Language

→ Visual cortex → **Vision**
~~Hearing~~
~~Touch~~
~~Language~~

Extra connections in sensory cortex

~~Eyes~~
Ears
Skin

→ Visual cortex →

Hearing
Touch
Language

Kujala et al. 1995
Leclerc et al. 2000
Liotti et al. 1998
Röder et al. 1999, 2000, 2002

Burton et al. 2003
Amedi et al. 2003

Burton et al.. 2002, 2004
Gizewksi et al. 2003
Sadato et al. 1998, 2002
Melzer et al.2001

Experience prunes connections

→ Visual cortex → **Vision**

~~Hearing~~

~~Touch~~

~~Language~~

Any remaining connections inhibited

Non-Synaesthetes

Five days:

Sighted adults

Braille

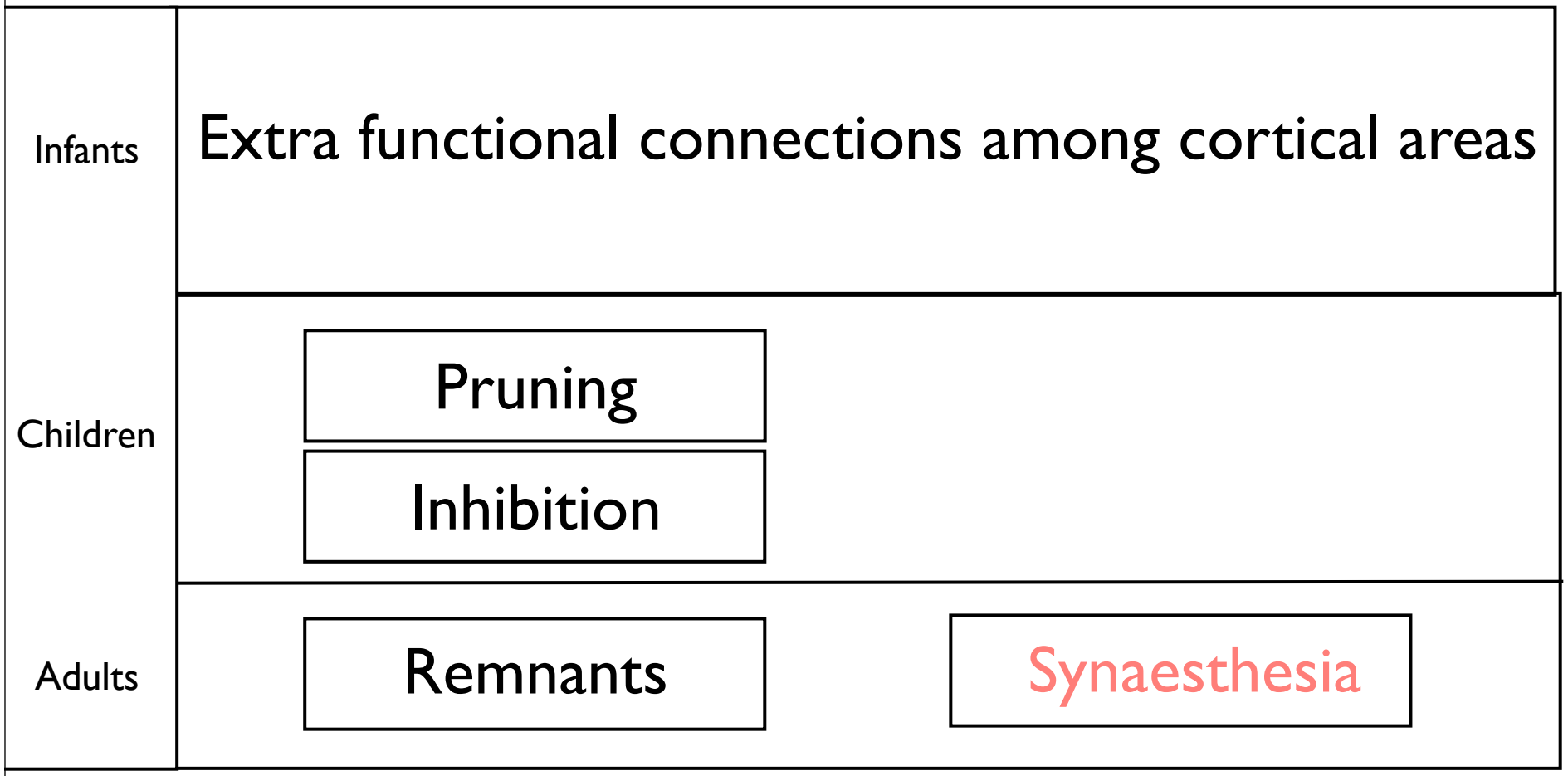
Vibration

Sound location

Tone frequency

Visual cortex

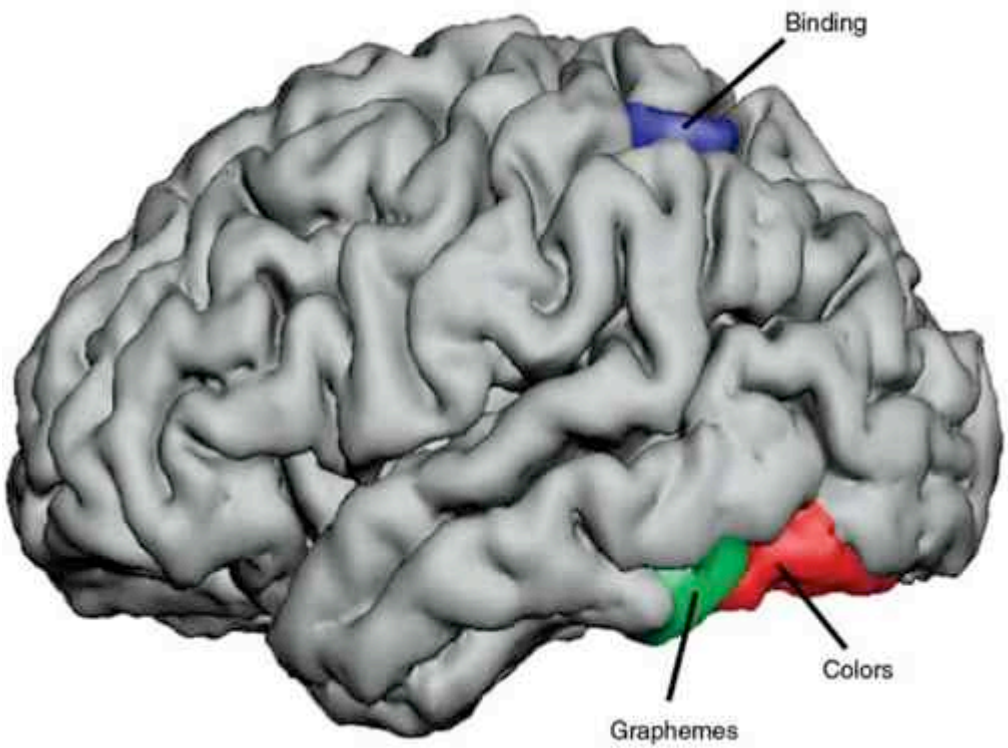
Burton et al. 2002
Kauffman et al. 2002
Sadato et al. 2004
Pascual-Leone & Hamilton 2001



Lead to *natural associations*

Synaesthesia: What's different?

- Less pruning
  - Colour grapheme synaestheses: More white matter beside V4/V8 and parietal cortex



Rouw & Scholte, 2007

Synaesthesia: What's different?

- Less pruning
  - Colour grapheme synaestheses: More white matter beside V4/V8 and parietal cortex
- Less effective inhibition
  - Acquire new synaesthetic connections when learn new alphabet, try new food, learn new language, after hypnosis
  - LSD
  - Enhanced with cortical depressants

Cohen-Kadosh, 2009
Rouw & Scholte, 2007
Mills et al., 2002
Ward & Simner, 2003
Winawer & Witthoft, 2004

Infants	Extra functional connections among cortical areas	
Children	Pruning	Less pruning
	Inhibition	Less inhibition
Adults	Remnants	Synaesthesia

Lead to *natural associations*

Natural associations in toddlers

Pre-literate

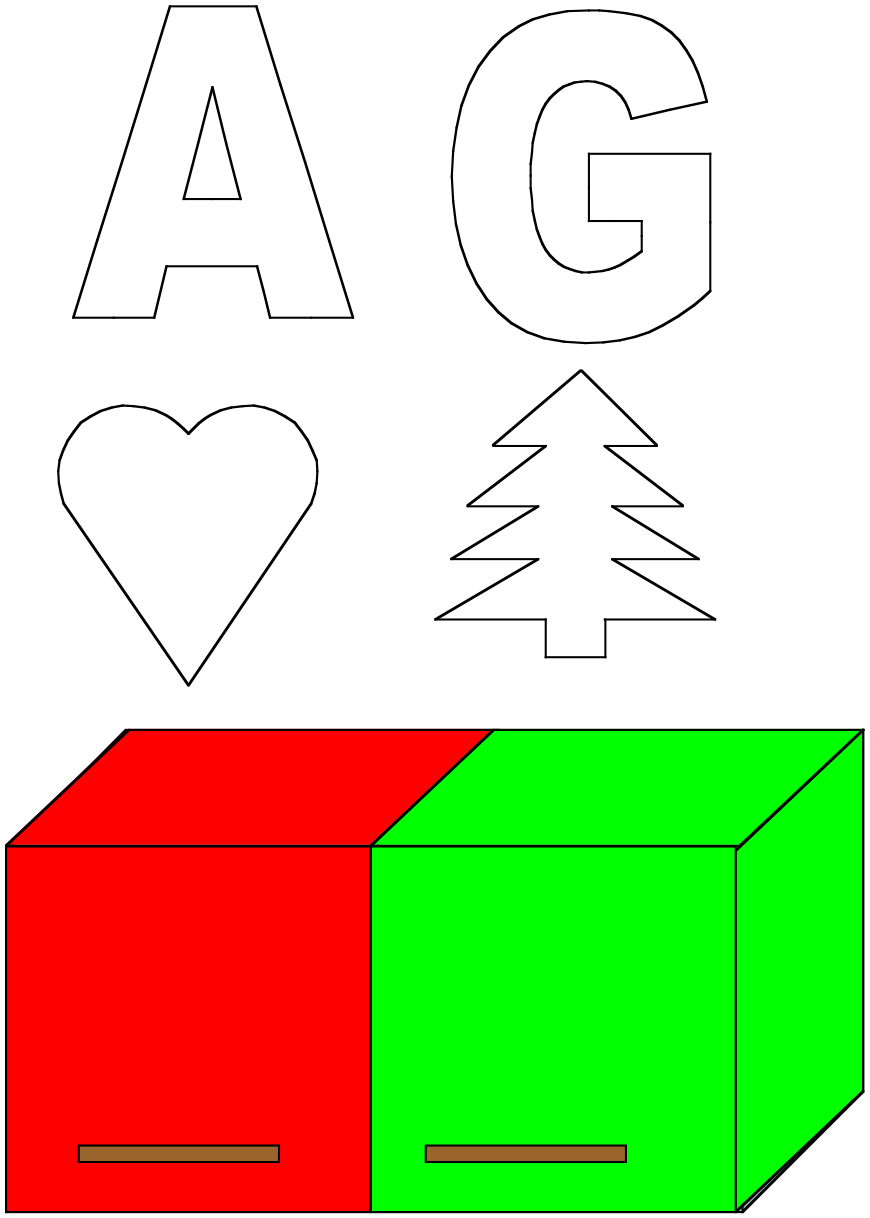
Learning language

Letters ~ colour

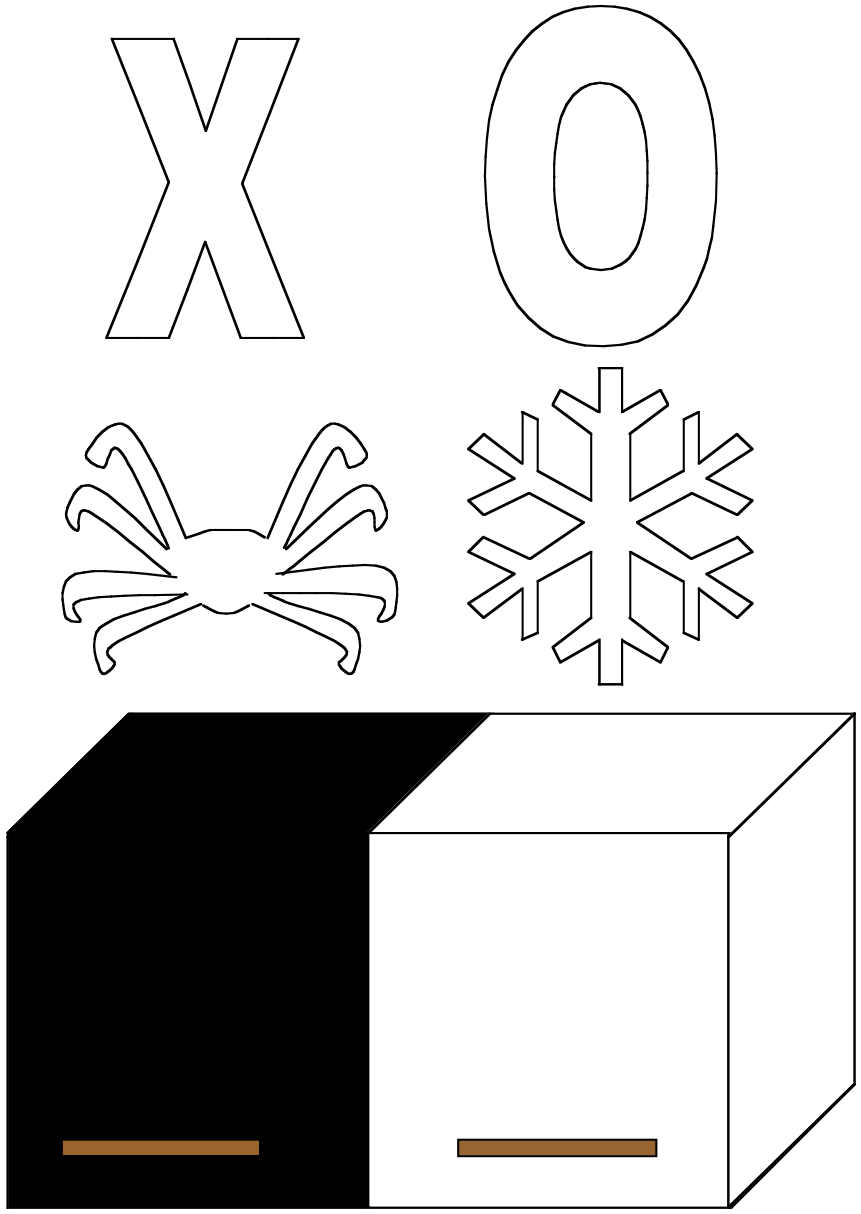
Non-synaesthetes ~ synaesthetes

(Day, 2001, 2005; Spector, 2003; Rich, Bradshaw, & Mattingly, 2005;Simner et al., 2005)

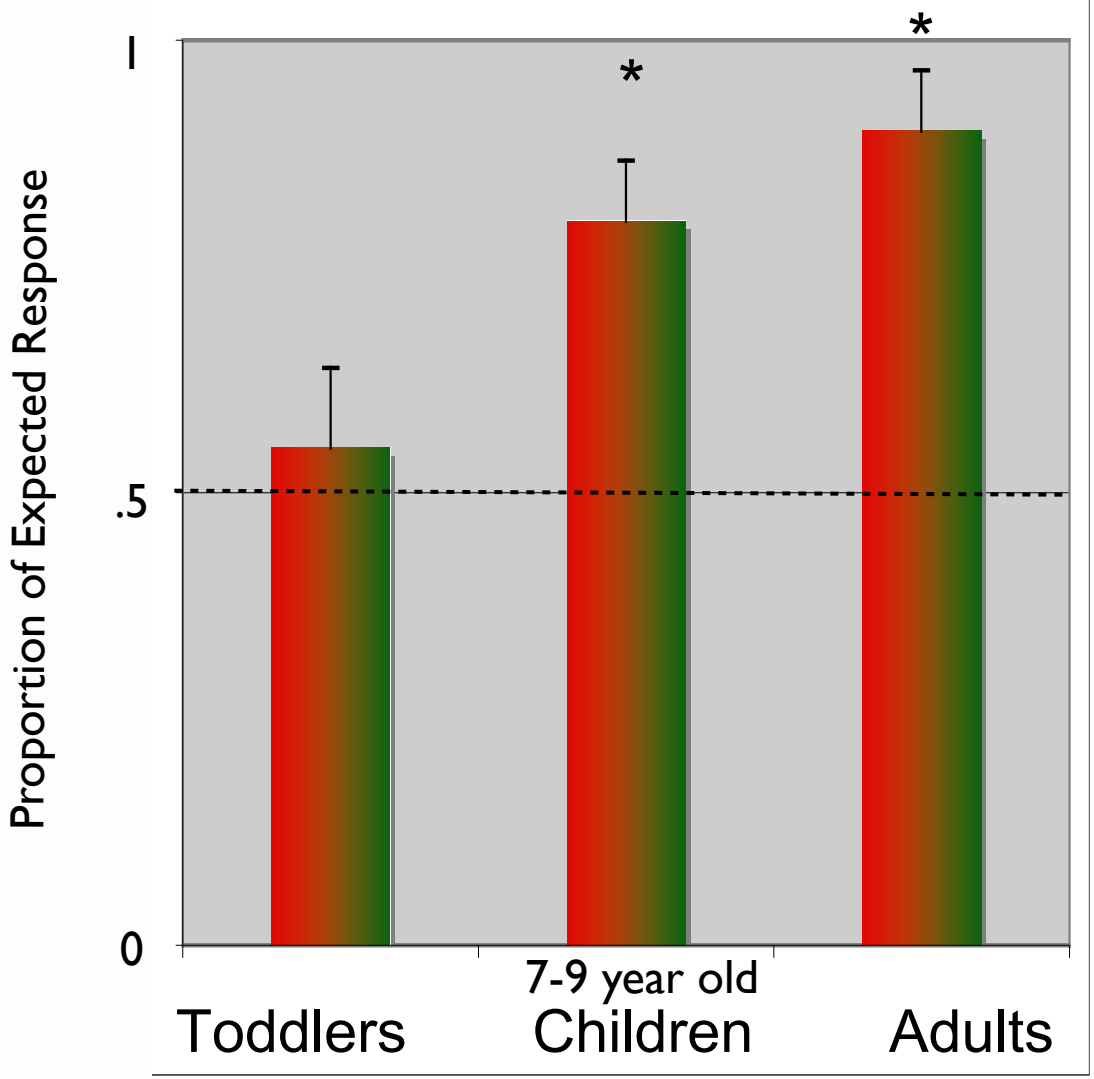
Red/Green



White/Black



A/G



Spector & Maurer, 2008

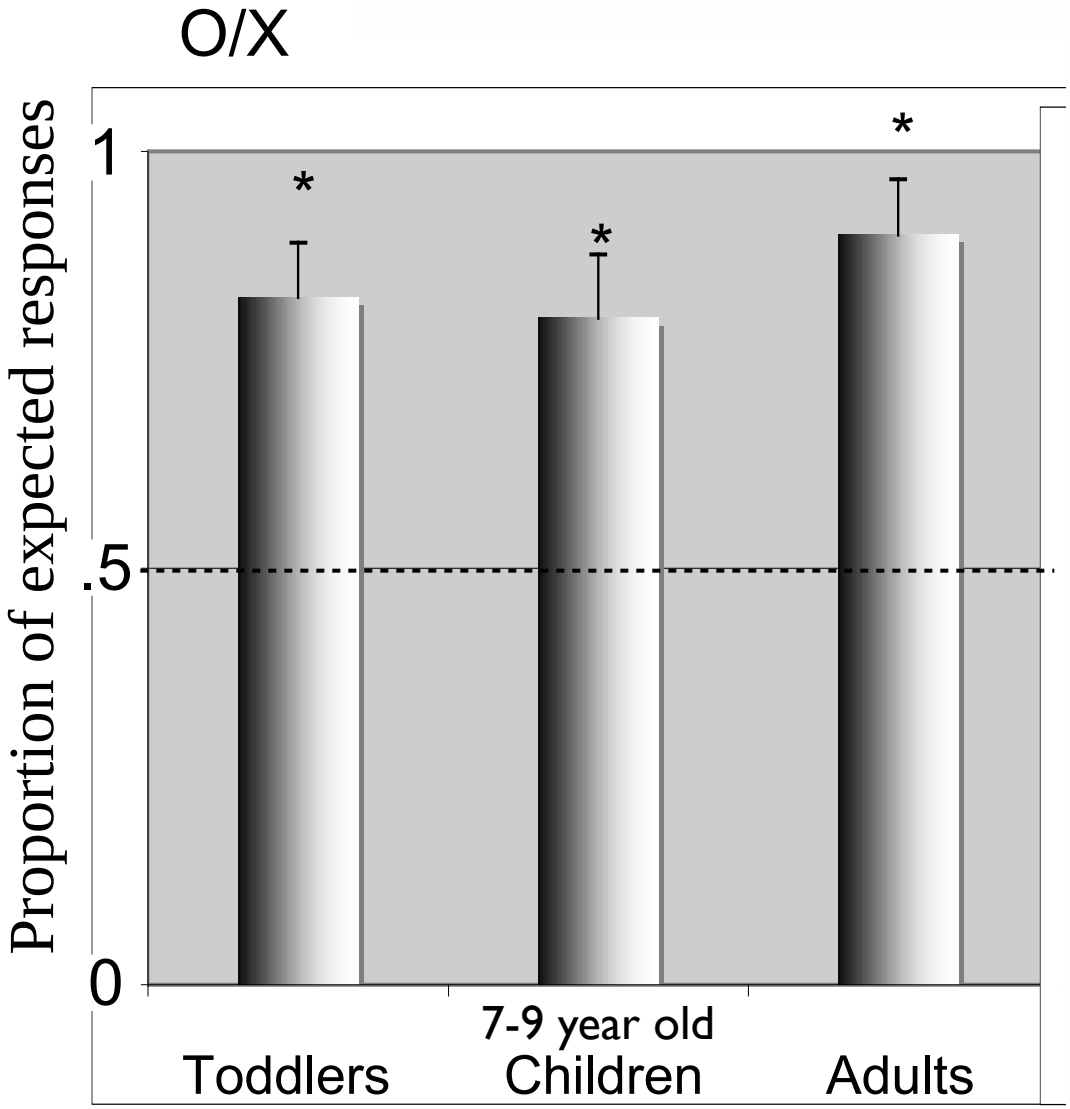
Learned associations in *non*-synaesthetes

Shape - colour

- Based on experience
- Change with reading

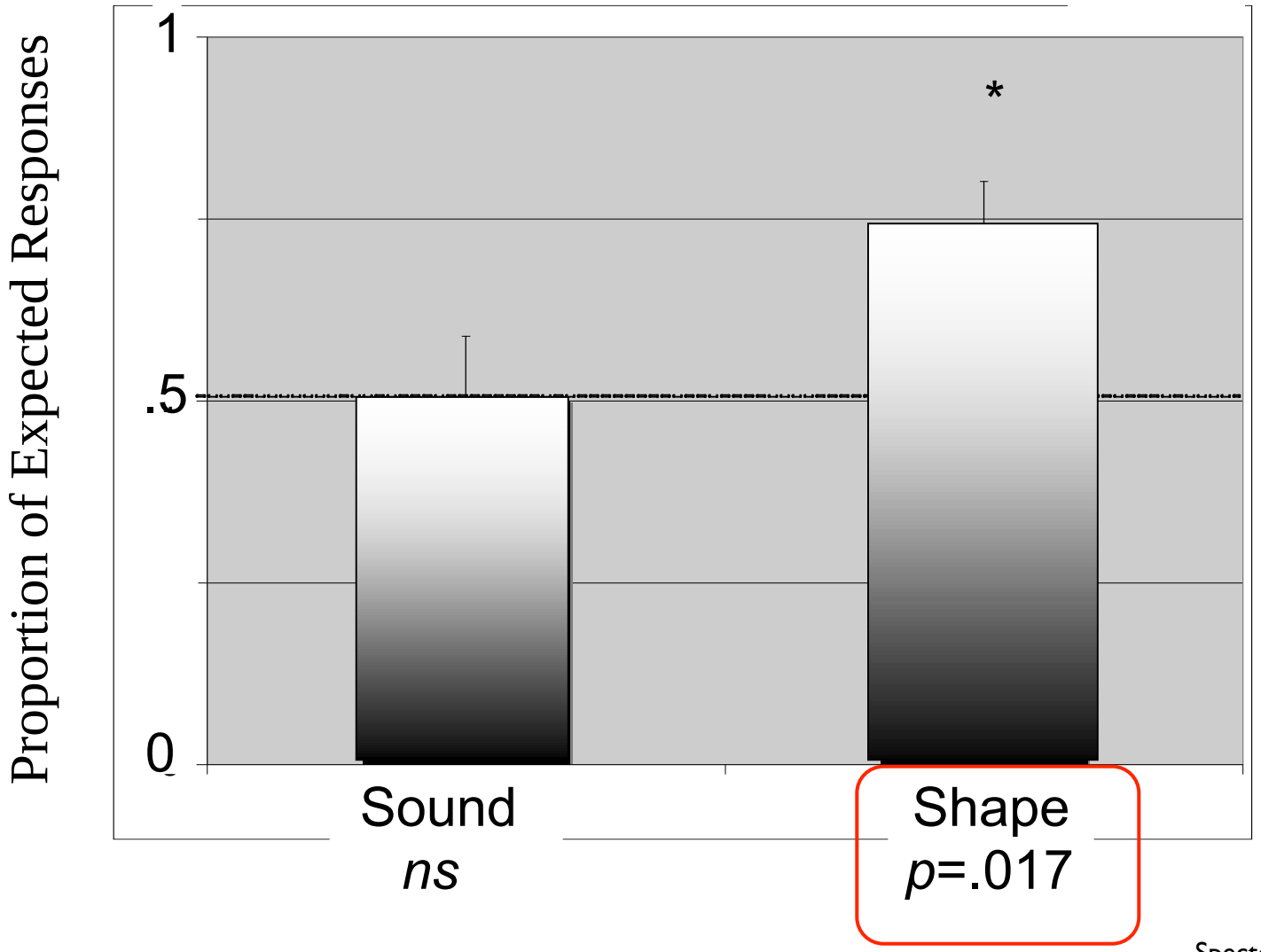
A G B Y

Spector & Maurer, 2008
Spector & Maurer, submitted



Spector & Maurer, 2008

O/X: Toddlers

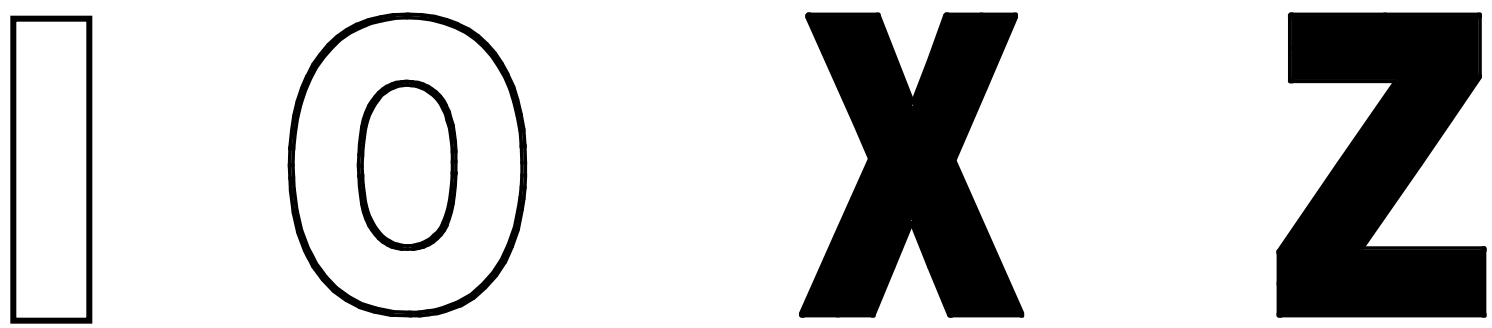


Spector & Maurer, 2008

Natural associations in *non*-synaesthetes

Shape - colour

- Not based on learning
- Like synaesthetes
- Reflect initial brain organization



Spector & Maurer, 2008
Spector & Maurer, submitted

Natural associations in *non*-synaesthetes

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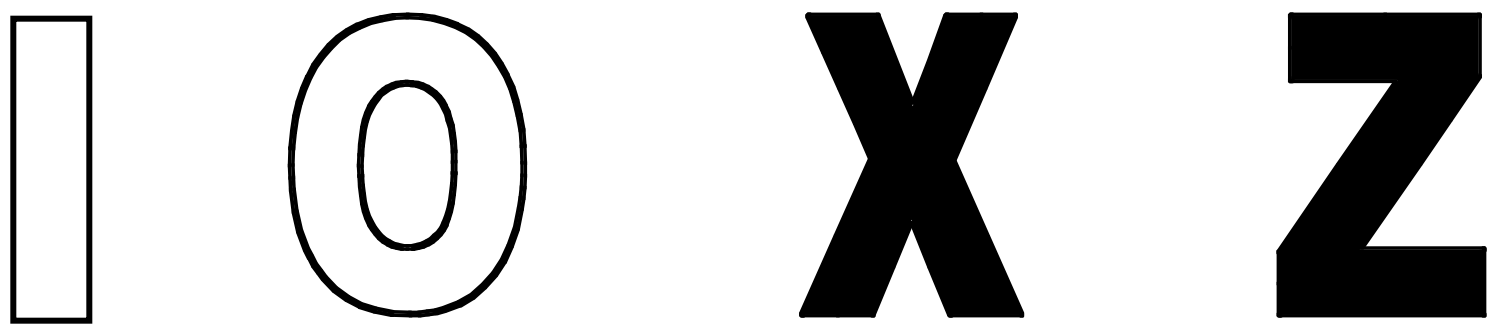
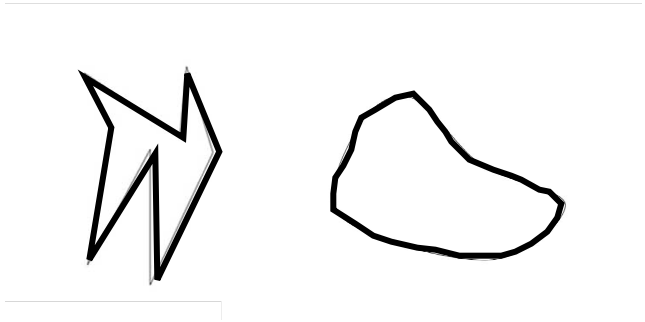
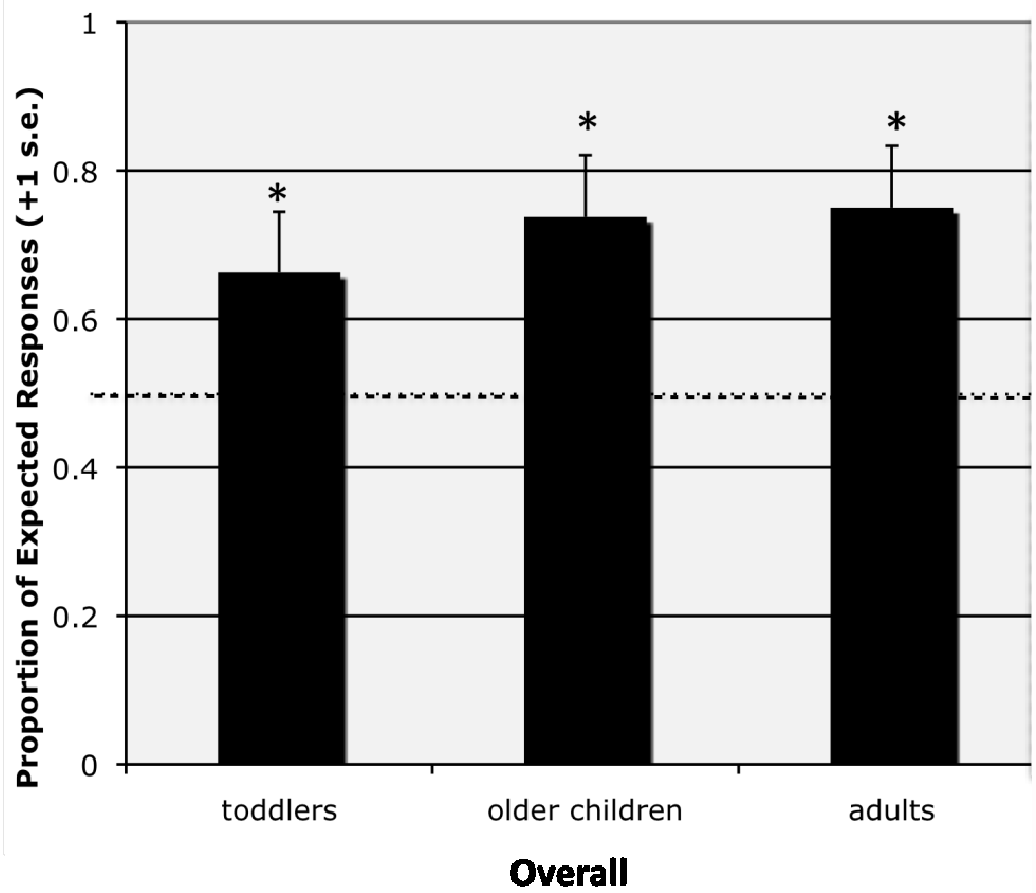


smooth? jagged?





Spector & Maurer, submitted

Natural associations in *non*-synaesthetes

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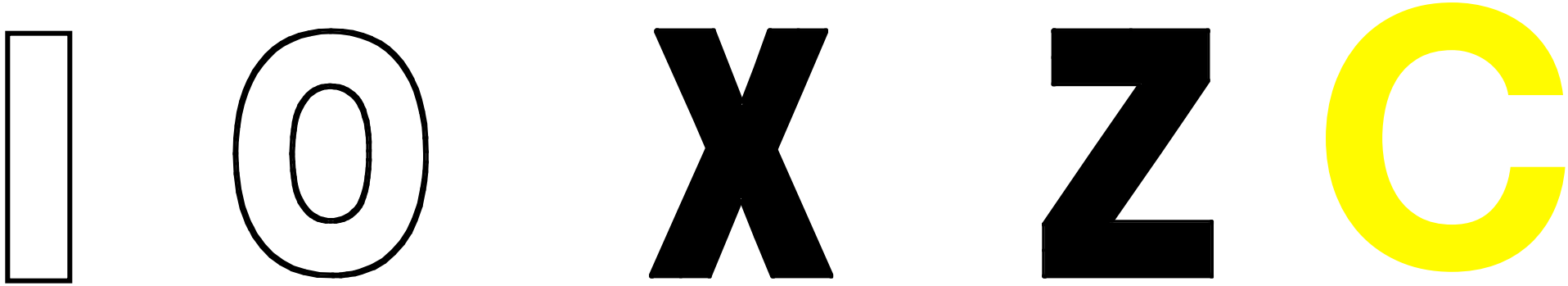


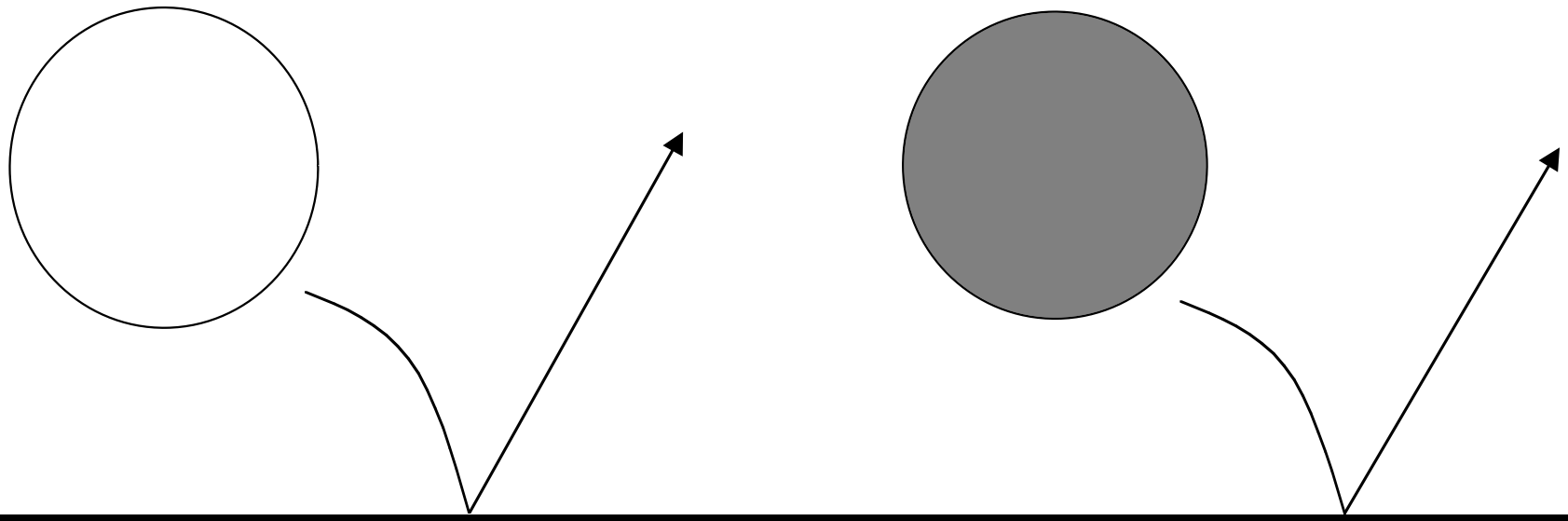
smooth

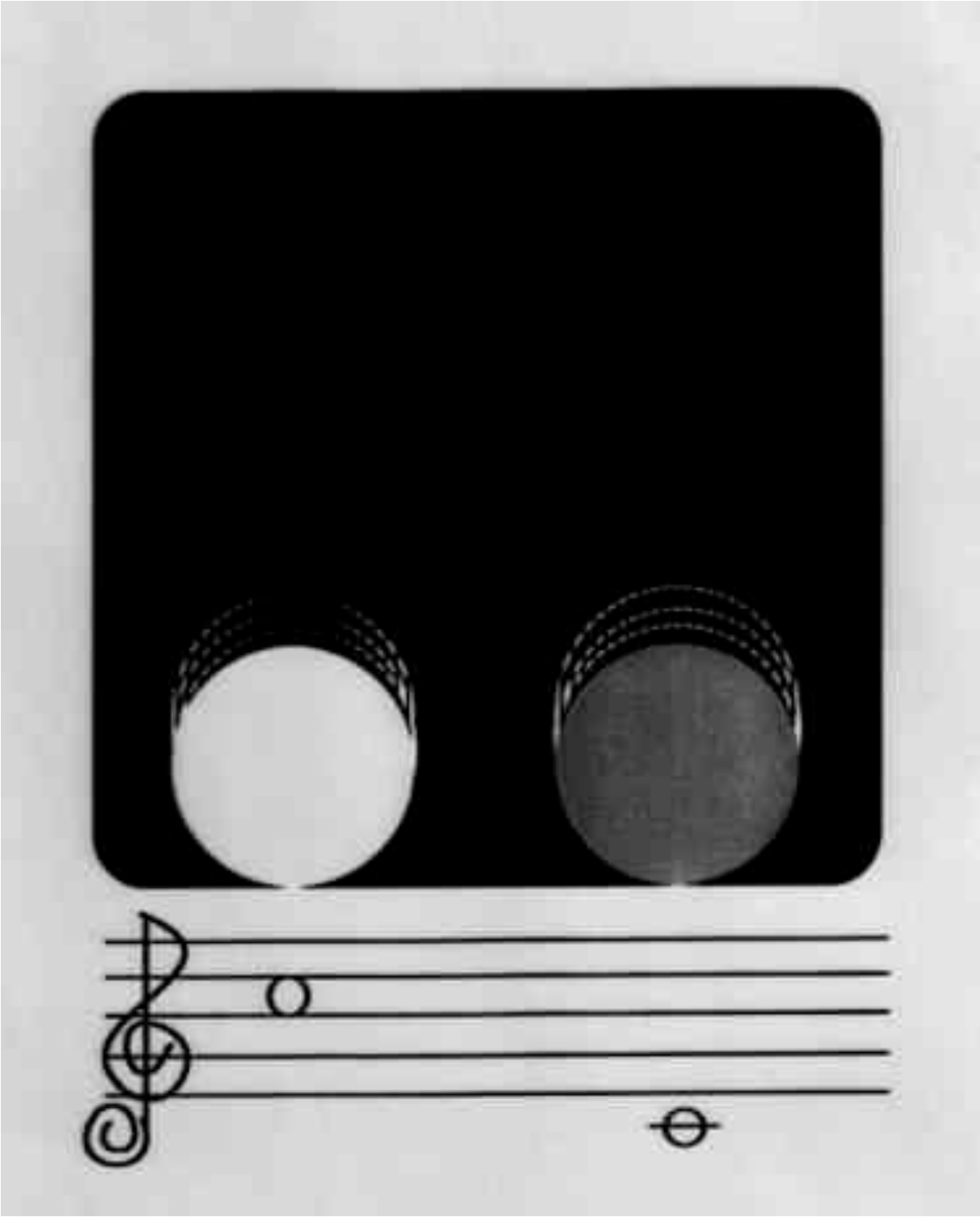
jagged

Spector & Maurer, 2008
Spector & Maurer, submitted

Pitch ~ lightness

Which one goes ping? Which goes pong?

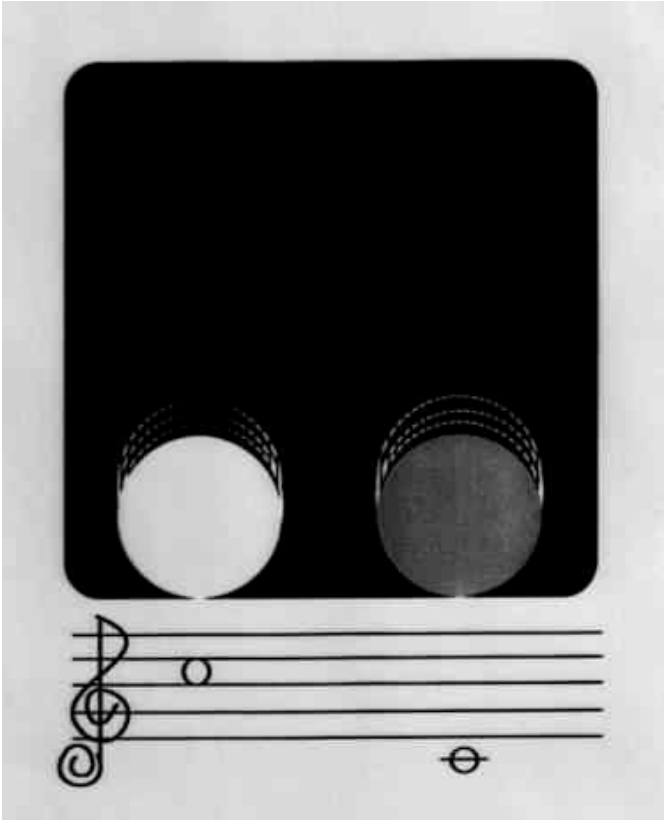




Ask toddlers,
"Which makes the sound?"

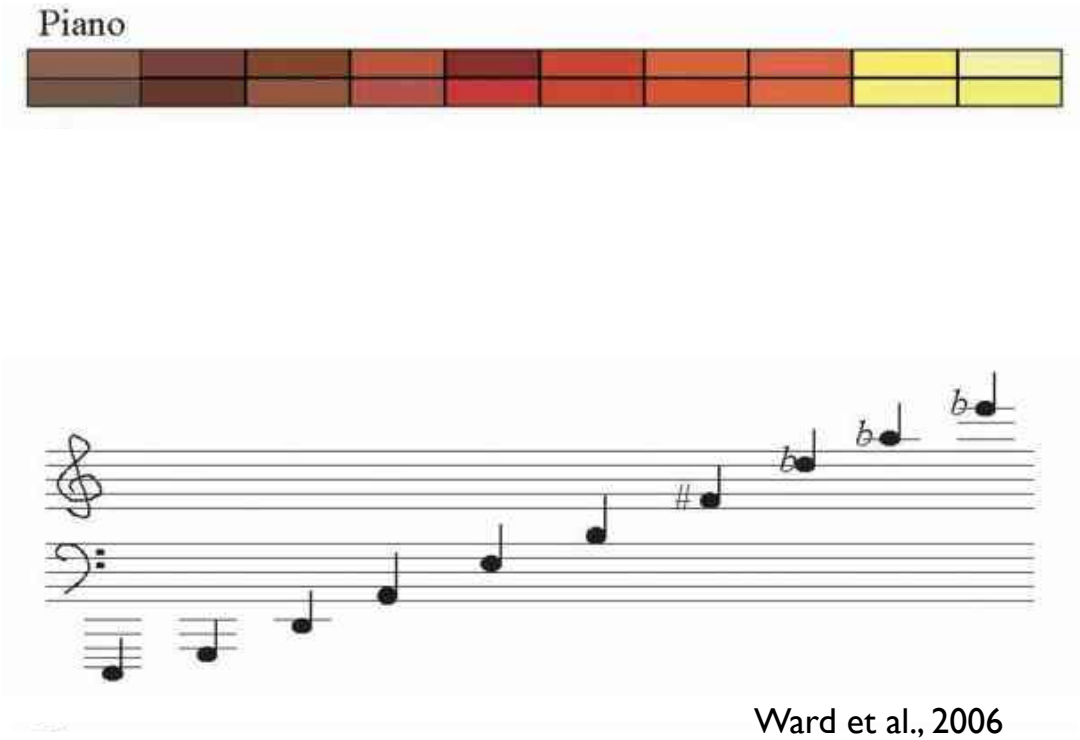
Mondloch & Maurer, 2004

Toddlers ~ synaesthetes



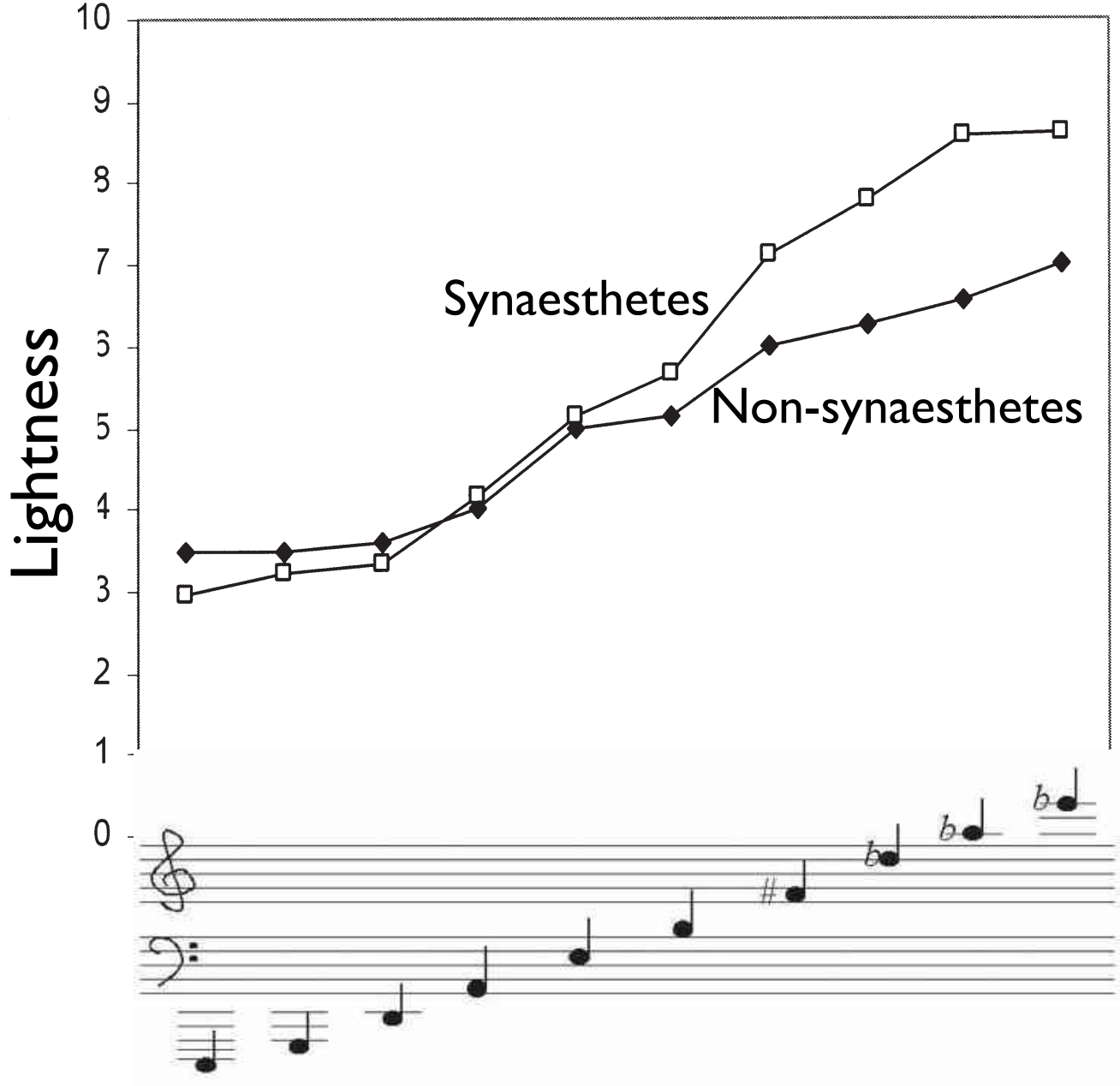
Lighter = higher pitch

Like synaesthetes
*who **see** pitch*



Ward et al., 2006

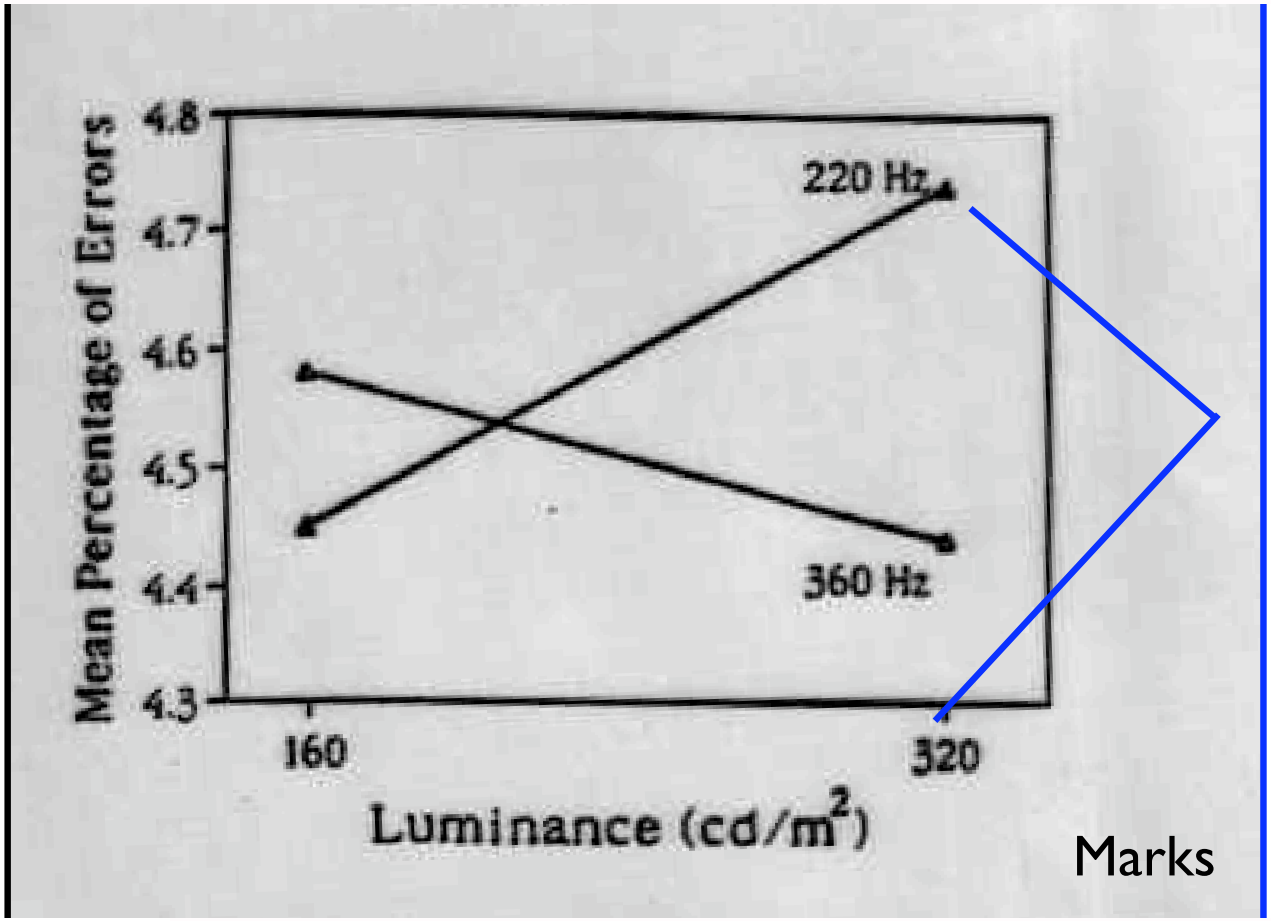
Non-synaesthetes ~ synaesthetes



Ward et al., 2006

Influences perception unconsciously

Non-synaesthetic adults



Marks

Errors

Darker

Lighter

Marks, 1987

Natural associations in *non*-synaesthetes

Pitch-lightness

- Not based on learning

Dark animals don't consistently make lower pitched sounds.

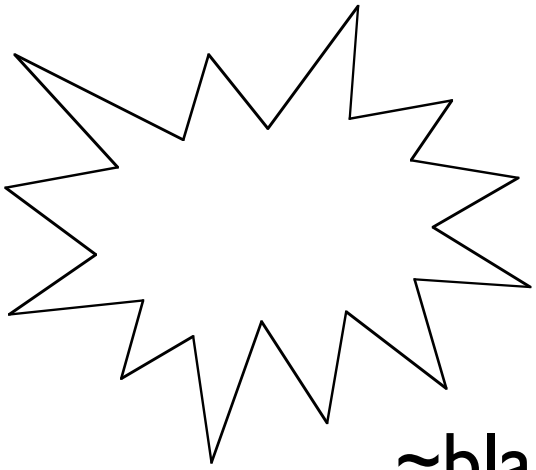
- Like synaesthetes
- Reflect initial brain organization

Sound ~ Shape

Infant as Synaesthete

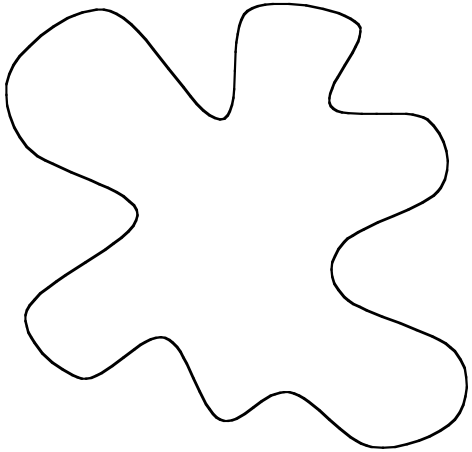
- Ramachandran: Influences evolution/development of language by linking:
  - Visual shape
  - Lip shape
  - Feeling in mouth during production
  - Gesture
- Connections adjacent sensory and motor cortical areas
- Mirror neurons: producing, seeing, hearing action

Maluma



~black

Takeeti



~white

Köhler, 1947

Ramachandran & Hubbard, 2005

Rounded vowels vs. non-rounded vowels

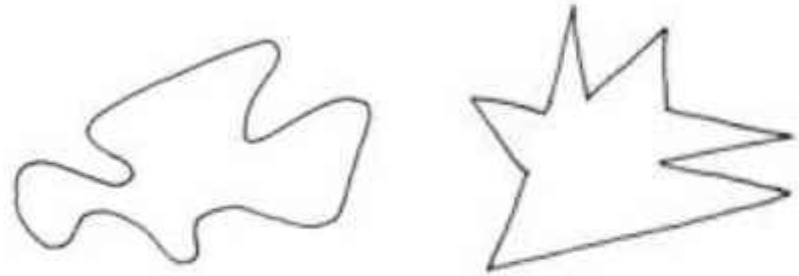
bamu	kutay
bouba	kayki
goga	titay
mabuma	taketee

Non-synaesthetes: vowel sound/shape

Shapes that activate different V4 neurons

1

2



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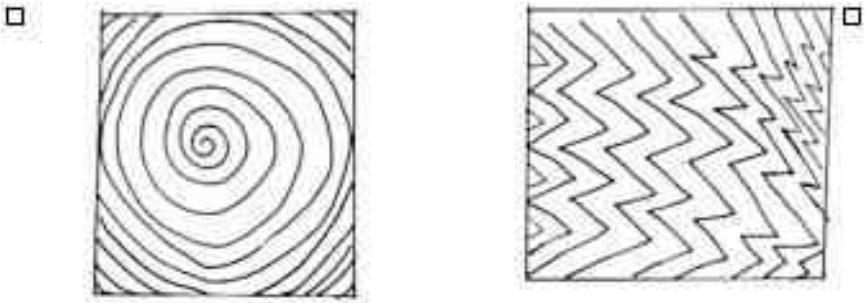

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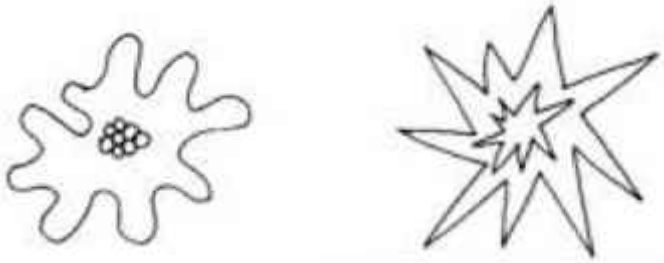
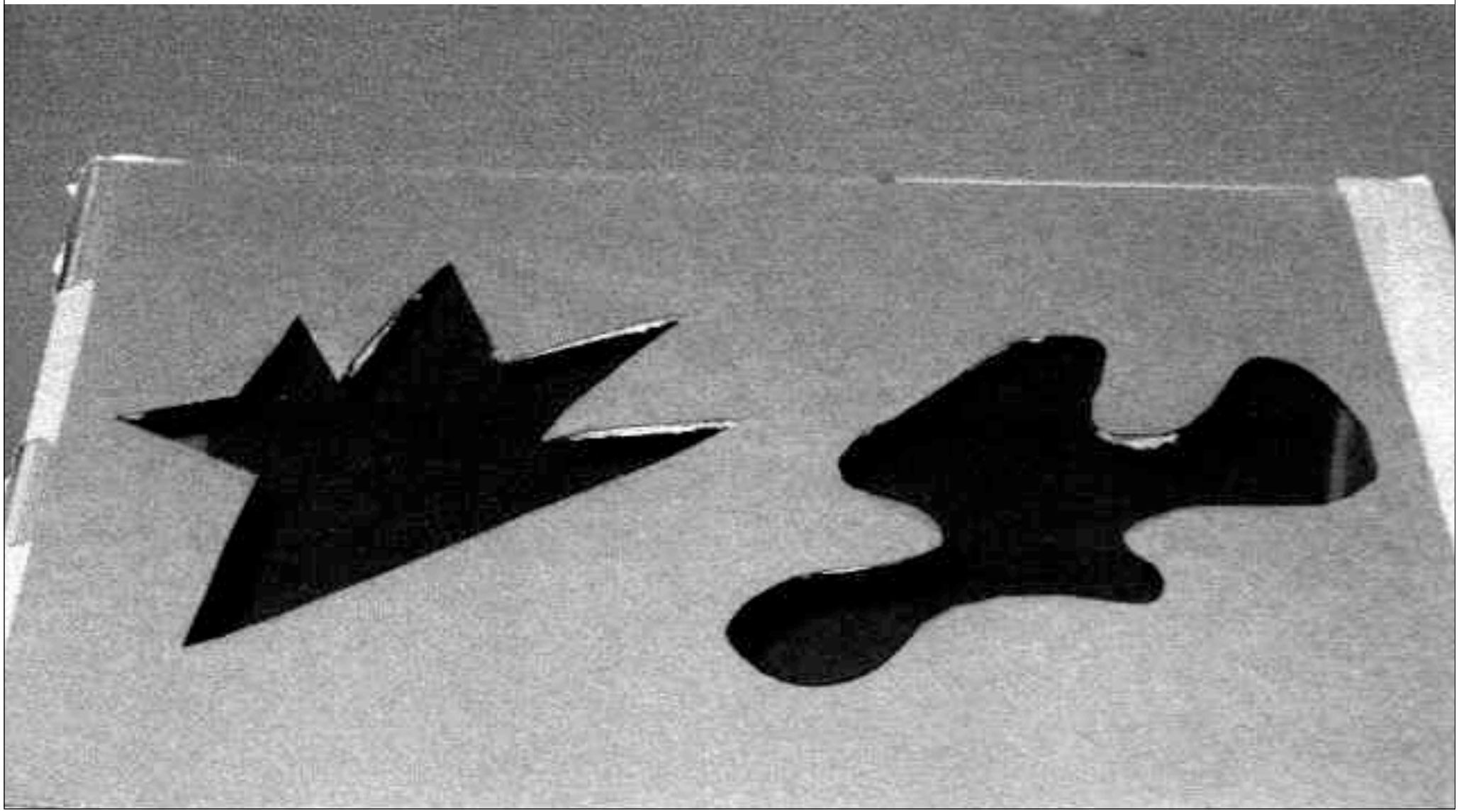
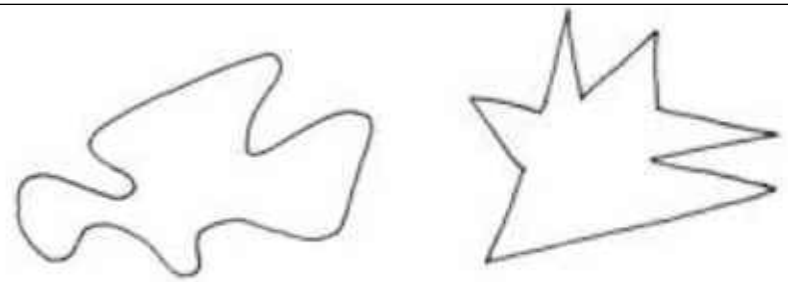


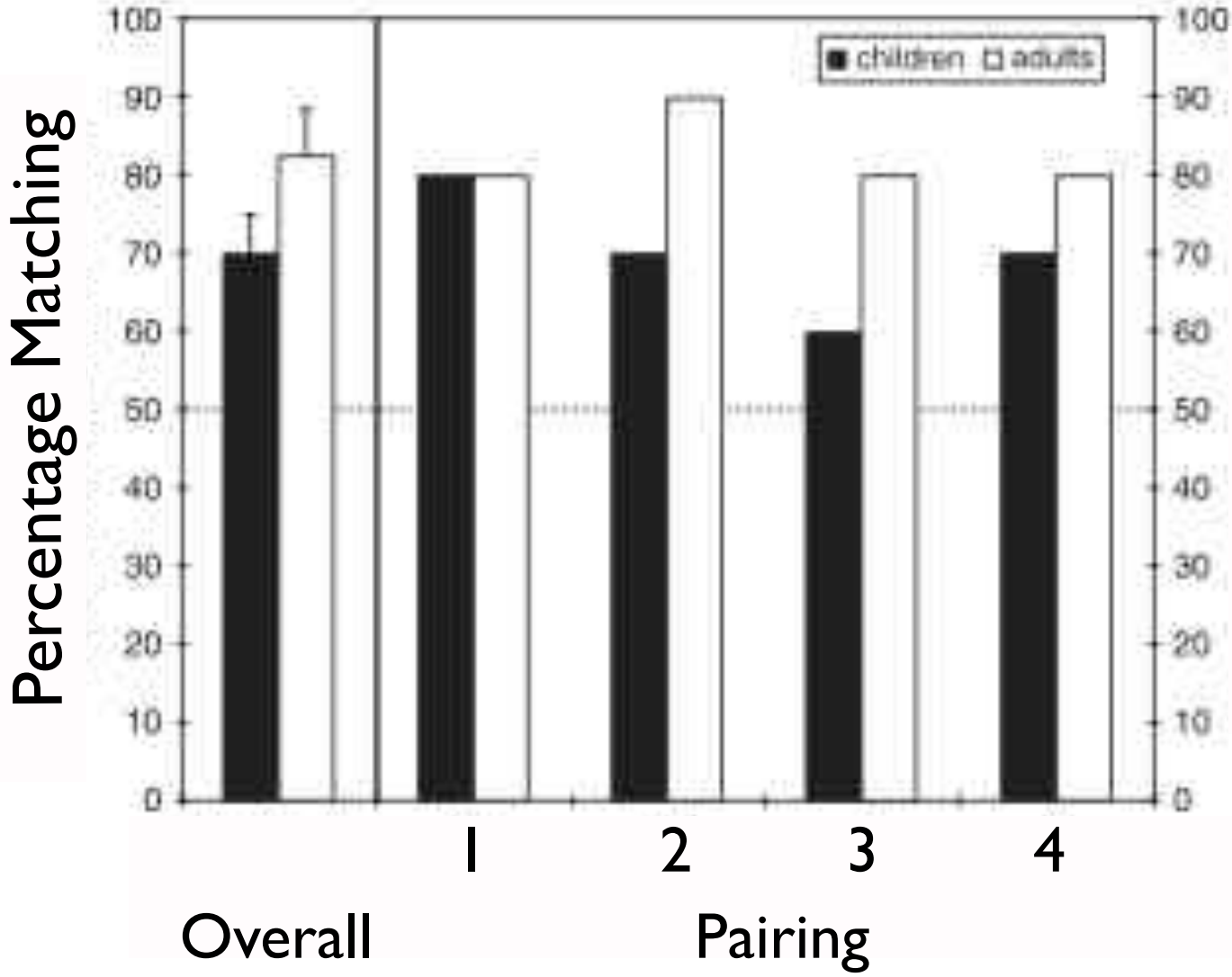
Maurer, Pathman, & Mondloch, 2006

kiki

bouba







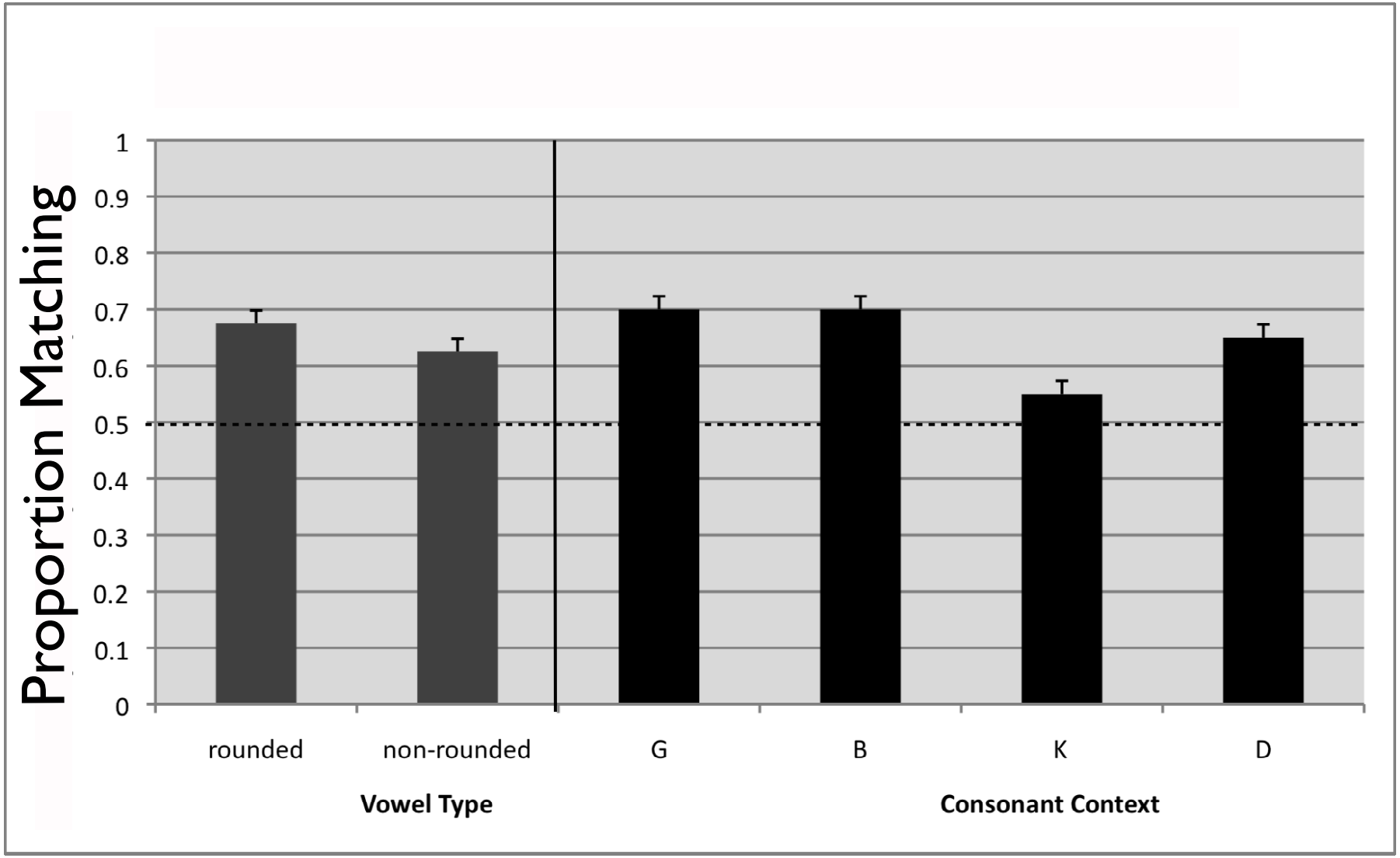
Maurer, Pathman, & Mondloch, 2006

Rounded vowels vs. non-rounded vowels

gigi	gogo
bibi	bobo
kiki	koko
didi	dodo

Spector & Maurer, in prep

Toddlers



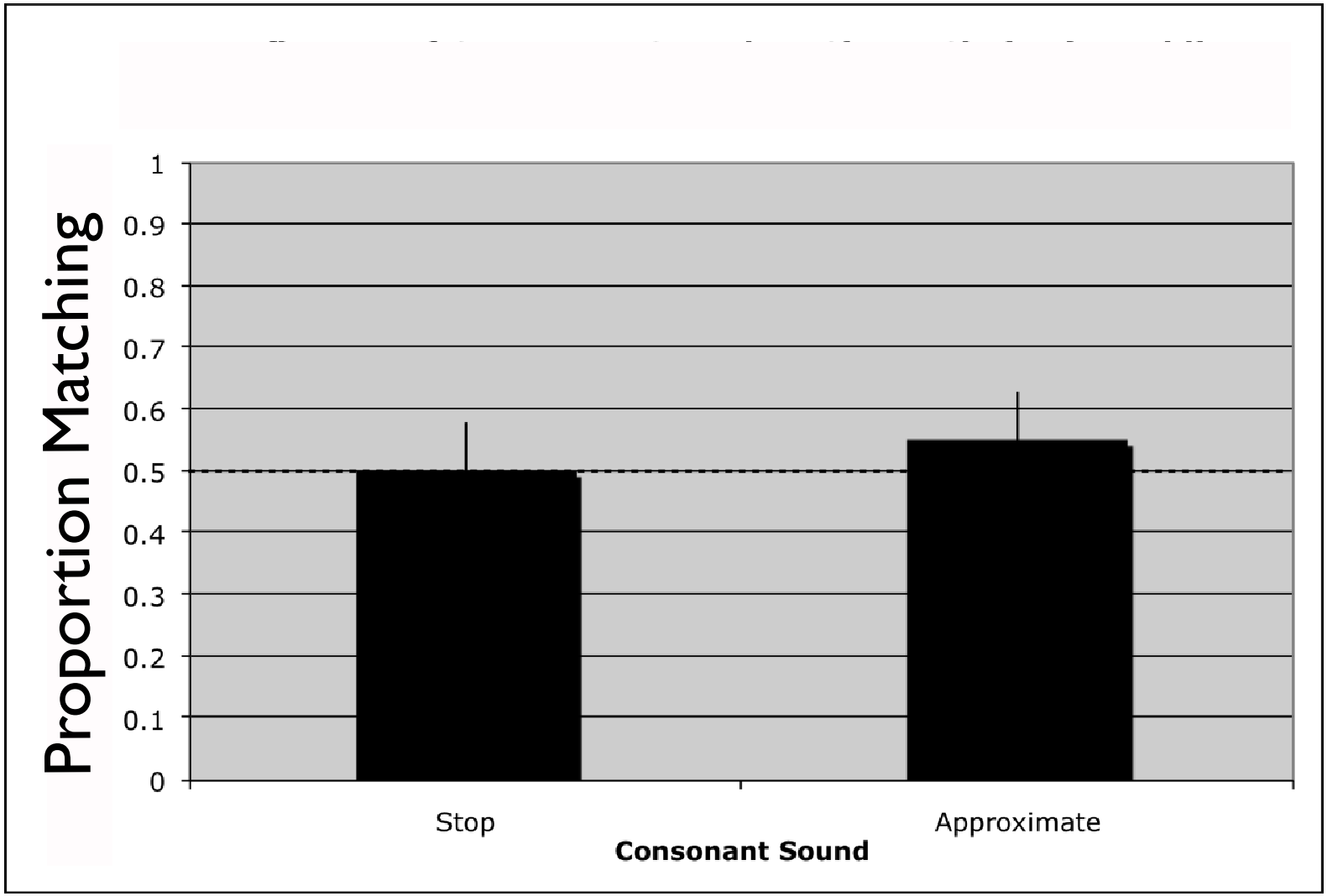
Spector & Maurer, in prep

Approximate versus Stop Consonants

Rounded vowels	
roro	bobo
lolo	gogo
wowo	koko
yoyo	dodo

Non-rounded vowels	
riri	bibi
lili	gigi
wiwi	kiki
yiyi	didi

Toddlers



Spector & Maurer, in prep

Natural associations in *non*-synaesthetes

Sound-shape

Rounded shapes ⇒ rounded vowels (ah, oh)

Jagged shapes ⇒ unrounded vowels (ee, i)

No effect for stop/approximant consonants

- Learning statistics of language or

....helping to learn language?

Maurer et al., 2006

Spector & Maurer, in prep

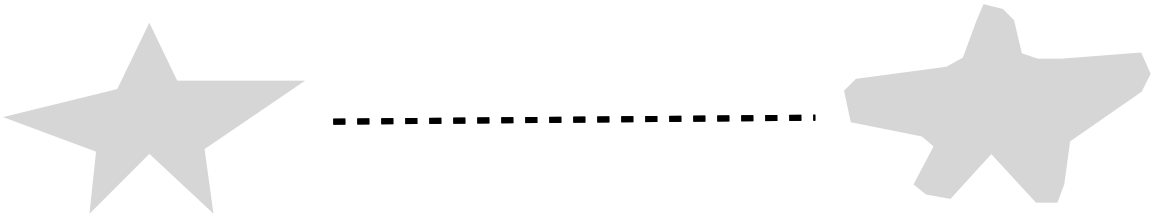
Natural associations in *non*-synaesthetes

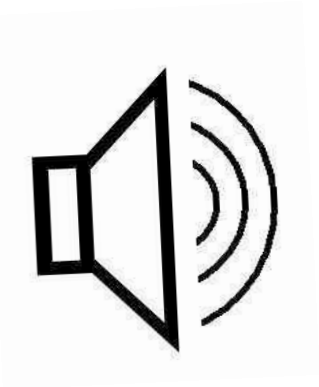
Sound-shape: what is effective cue?

- Heard sound?
- Sight of lips moving to make sound?
- Feeling of making sound oneself?

Infants link sound (pitch) to shape

3- to 4-month-olds





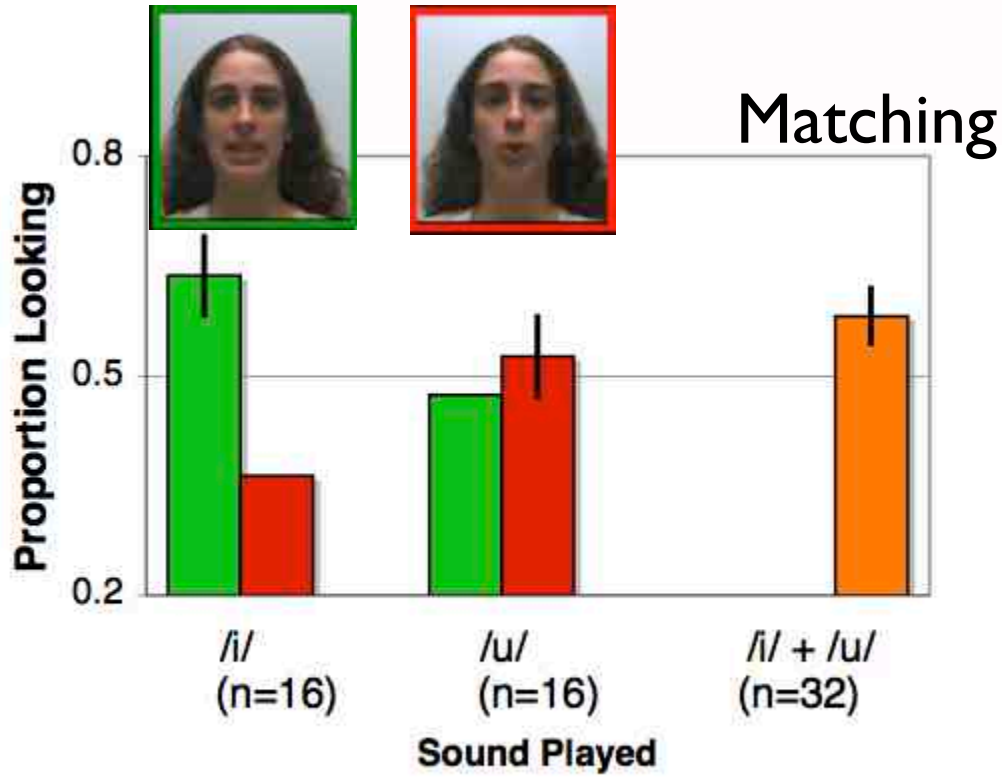
1700 Hz ---------- 300 Hz

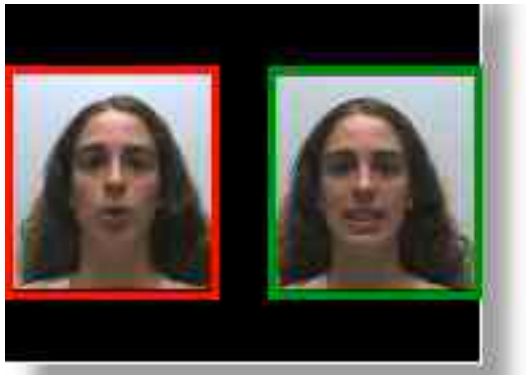
300 Hz ---------- 1700 Hz

Up..... Down

Walker et al., 2010

Infants link sound to lip movements





2 min
(vowel played)

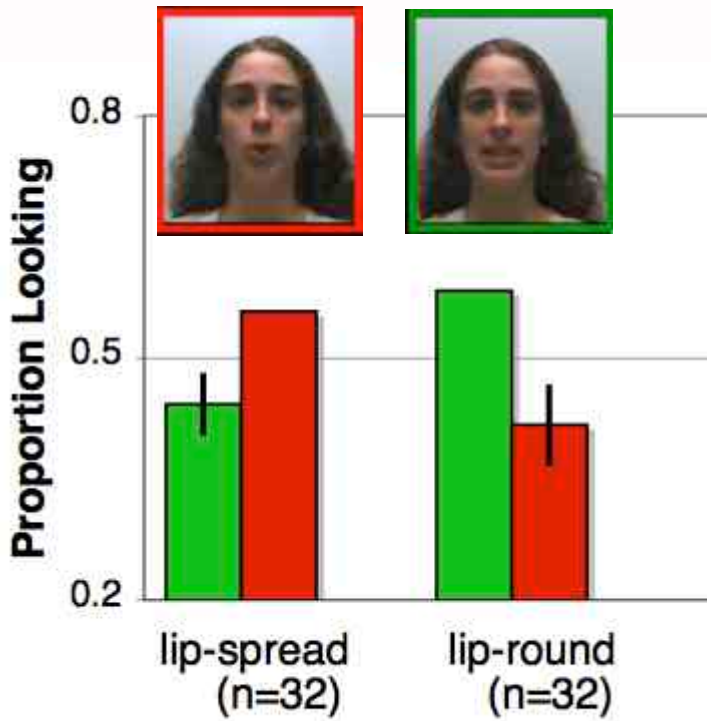
4-month-olds

Yeung & Werker, 2010

Infants link mouth movements to shape?

lip-spreading

lip-rounding



Contrast effect

Yeung & Werker, 2010

Adults link mouth movements to shape

had ---------- *head*

Down Up

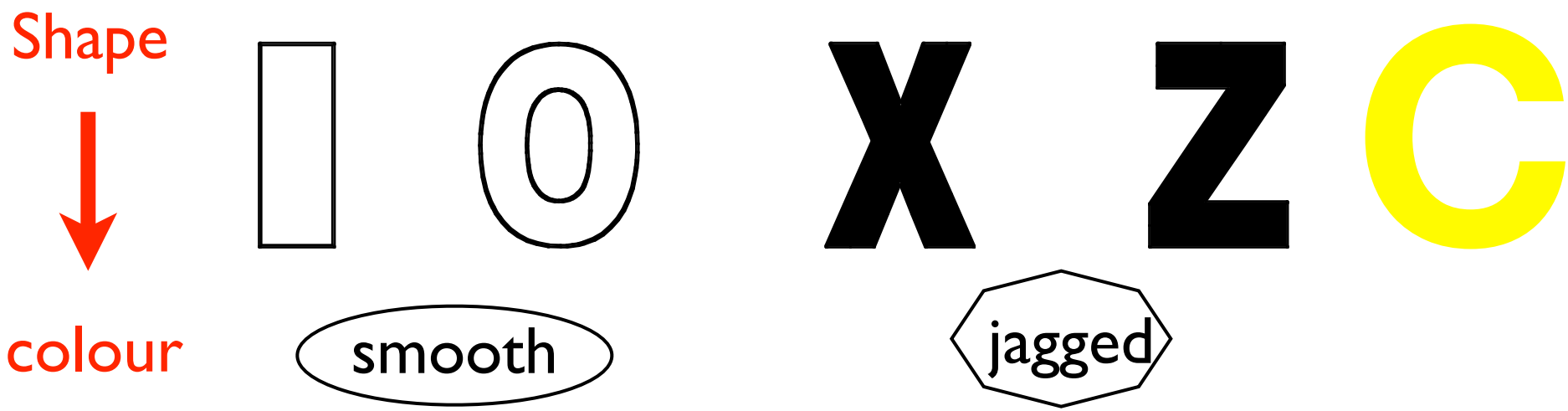
Ito, Tide, & Ostry, 2009

Natural associations in *non*-synaesthetes

Sound-shape links could be based on

- Heard sound
- Sight of lips moving to make sound
- Feeling of making sound oneself

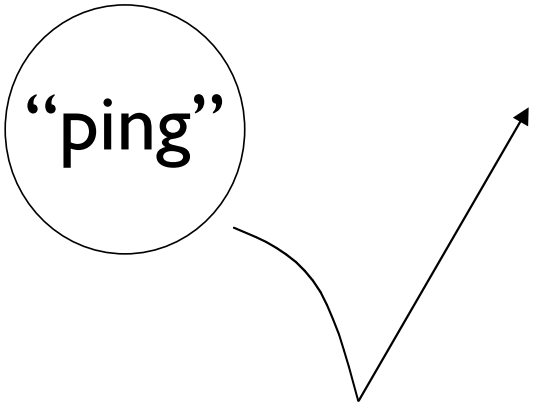
Synaesthetic influences in toddlers and adults

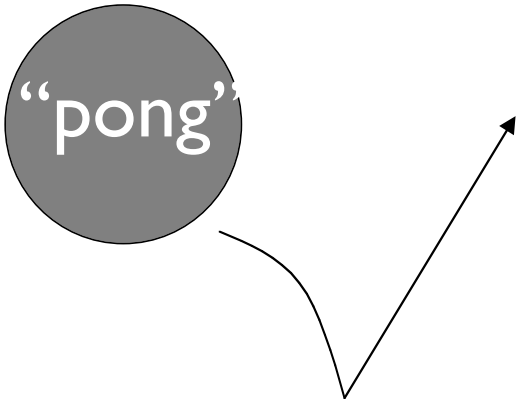


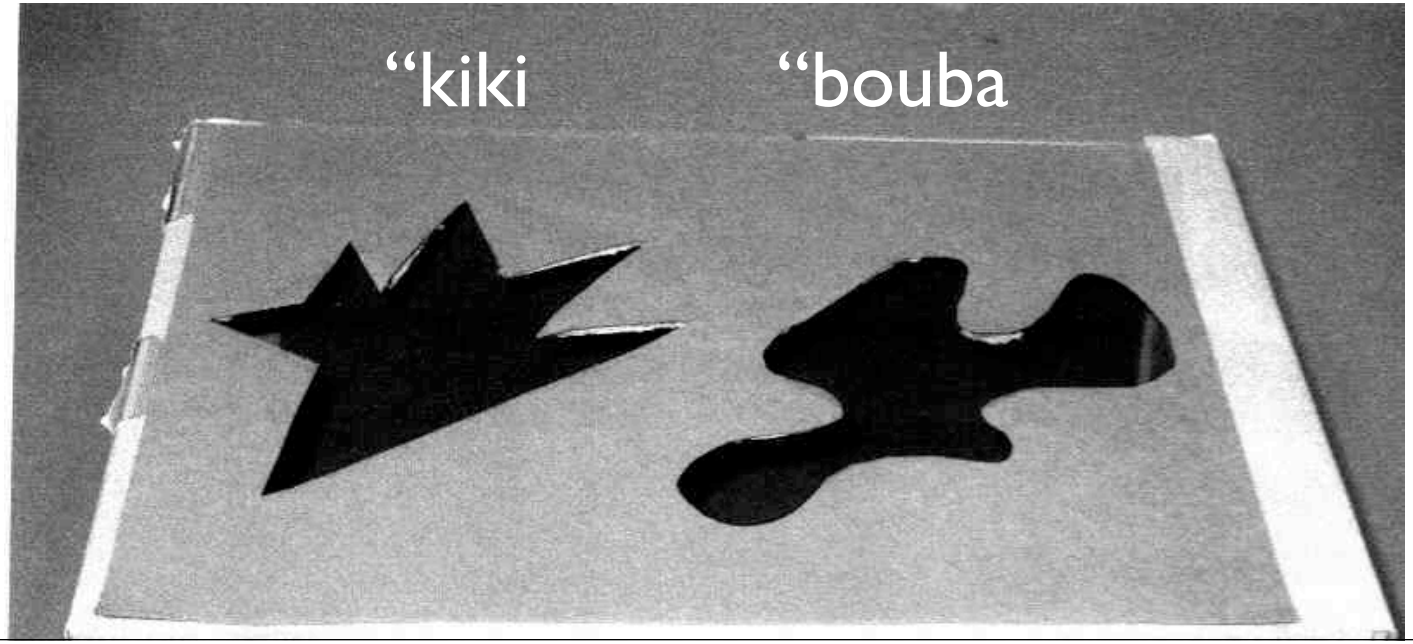
Synaesthetic influences in toddlers and adults

Hearing

vision







Synaesthesia:
A New Perspective for Understanding the Development of Perception and Even Language

Language learning alters synaesthetic matching

(e.g., Smith & Sera)

	2-year-olds	3-year-olds
Comprehension *big/little, loud/quiet, dark/light*	Inconsistent	Good
Visual matching *big/little to dark/light*	*Big=dark* *Little=light*	Inconsistent
Visual matching *big/little to loud/quiet*	Inconsistent	Big=loud Little=quiet

Non-synaesthetes: vowel sound/shape

- May influence evolution/development of language
  - "round"
  - "spikey"

Ramachandran & Hubbard, 2001

- Intersensory metaphors parallel synaesthesia
  - *loud* necktie (from hearing to vision)
  - *sharp* cheese (from touch to taste)

Sean Day

- Can guess meanings of words in foreign languages

Berlin, 1964