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)
Synaesthesis: ~54 types

Sound of C# on a flute

⇒

⇒

⇒ 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

\[ \begin{align*}
2 & \quad W & \quad \Rightarrow & \quad \text{Red} \\
5 & \quad P & \quad \Rightarrow & \quad \text{Blue} \\
4 & \quad H & \quad \Rightarrow & \quad \text{Green}
\end{align*} \]
Coloured letters and digits

Adapted from Pat Duffy, *Blue Cats and Chartruese Kittens*
Synaesthesia

Sound of a trumpet

⇒

⇒

⇒ *taste of oranges not quite ripe*

• Automatic

• “All their lives”

• Mappings are consistent over years.

• Runs in families
Runs in families

4-year-old

Her mother

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
Easy

5 2 2 5
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

Sound → Sounds → Colour V4/V8

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

Sperling et al., 2006
Synaesthesia: result of normal developmental process
Transient connections between sensory cortices

• Kitten
  • Auditory ⇔ visual ⇔ tactile ⇔ motor cortex

• Infant monkey
  • Auditory cortex ⇒ 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

R inferior temporal gyrus (FFA) - PET - L auditory temporal cortex
L Broca’s area

Tzaourio-Mazoyer, de Schonen et al. 2002
Neural Development

- Functional connections between sensory areas
  - Modified throughout development by pruning and inhibition.
- Extra functional connections among cortical areas

**Early childhood**

**Synaesthesia**

Extra functional connections among cortical areas
Experience prunes connections
Extra connections in sensory cortex

Gizewski et al. 2003
Burton et al. 2002, 2004
Melzer et al. 2001
Sadato et al. 1998, 2002
Liotti et al. 1998
Kujala et al. 1995
Leclerc et al. 2000
Röder et al. 1999, 2000, 2002
Amedi et al. 2003
Burton et al. 2003
Experience prunes connections

Any remaining connections inhibited
Five days: Non-Synaesthetes

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
<table>
<thead>
<tr>
<th>Infants</th>
<th>Extra functional connections among cortical areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children</td>
<td>Pruning</td>
</tr>
<tr>
<td>Adults</td>
<td>Remnants</td>
</tr>
</tbody>
</table>

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
Extra functional connections among cortical areas

- Infants
  - Pruning
  - Inhibition
  - Remnants

- Children
  - Less pruning
  - Less inhibition

- Adults
  - Synaesthesia

Lead to *natural associations*
Natural associations in toddlers

Pre-literate
Learning language
Letters ~ colour
Non-synaesthetes ~ synaesthetes


A/G

Proportion of Expected Response

Toddlers  7-9 year old  Adults

Spector & Maurer, 2008
Learned associations
in non-synaesthetes

Shape - colour

• Based on experience

• Change with reading

\text{A} \quad \text{G} \quad \text{B} \quad \text{Y}

Spector & Maurer, 2008
Spector & Maurer, submitted
Proportion of expected responses

Spector & Maurer, 2008
Proportion of Expected Responses

O/X: Toddlers

Sound

ns

Shape

* p = .017

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

Shape - colour

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

smooth?  jagged?
Natural associations in non-synaesthetes

Shape - colour

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

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

Like synaesthetes who see pitch

Lighter = higher pitch

Ward et al., 2006
Non-synaesthetes ~ synaesthetes

Ward et al., 2006
Influences perception unconsciously
Non-syn-aesthetic adults

Darker Marks, 1987

Lighter

Errors

Mean Percentage of Errors

Luminance (cd/m²)

160 320

220 Hz

360 Hz

Marks

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
Match the words on the left to the figures on the right.

Maluma

Takeeti

Köhler, 1947
Ramachandran & Hubbard, 2005
Rounded vowels vs. non-rounded vowels

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>bamu</td>
<td>kutay</td>
</tr>
<tr>
<td>bouba</td>
<td>kayki</td>
</tr>
<tr>
<td>goga</td>
<td>titay</td>
</tr>
<tr>
<td>mabuma</td>
<td>taketee</td>
</tr>
</tbody>
</table>
Non-synaesthetes: vowel sound/shape

Shapes that activate different V4 neurons

Maurer, Pathman, & Mondloch, 2006
kiki
bouba
Percentage Matching

Overall | 1 | 2 | 3 | 4
---|---|---|---|---
Pairing

Maurer, Pathman, & Mondloch, 2006
## Rounded vowels vs. non-rounded vowels

<table>
<thead>
<tr>
<th>gigi</th>
<th>gogo</th>
</tr>
</thead>
<tbody>
<tr>
<td>bibi</td>
<td>bobo</td>
</tr>
<tr>
<td>kiki</td>
<td>koko</td>
</tr>
<tr>
<td>didi</td>
<td>dodo</td>
</tr>
</tbody>
</table>

Spector & Maurer, in prep
Toddlers

Spector & Maurer, in prep

Proportion Matching

Vowel Type
- rounded
- non-rounded

Consonant Context
- G
- B
- K
- D

Spector & Maurer, in prep
### Approximate versus Stop Consonants

<table>
<thead>
<tr>
<th>Rounded vowels</th>
<th>Non-rounded vowels</th>
</tr>
</thead>
<tbody>
<tr>
<td>roro</td>
<td>riri</td>
</tr>
<tr>
<td>bobo</td>
<td>bibi</td>
</tr>
<tr>
<td>lolo</td>
<td>lili</td>
</tr>
<tr>
<td>gogo</td>
<td>gigi</td>
</tr>
<tr>
<td>wowo</td>
<td>wiwi</td>
</tr>
<tr>
<td>koko</td>
<td>kiki</td>
</tr>
<tr>
<td>yoyo</td>
<td>yiyi</td>
</tr>
<tr>
<td>dodo</td>
<td>didi</td>
</tr>
</tbody>
</table>
Toddlers

Proportion Matching

Spector & Maurer, in prep
Natural associations in non-synaesthetes

Sound-shape

Rounded shapes $\Rightarrow$ rounded vowels (ah, oh)

Jagged shapes $\Rightarrow$ 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

Walker et al., 2010
Infants link sound to lip movements

Yeung & Werker, 2010

4-month-olds

Yeung & Werker, 2010
Infants link mouth movements to shape?

Contrast effect

Yeung & Werker, 2010
Adults link mouth movements to shape

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

Shape

colour

smooth

jagged
Synaesthetic influences in toddlers and adults

Hearing

“ping”

“pong”

vision

“kiki”

“bouba”
Synaesthesia:
A New Perspective for Understanding
the Development of Perception and
Even Language
Language learning alters synaesthetic matching
(e.g., Smith & Sera)

<table>
<thead>
<tr>
<th></th>
<th>2-year-olds</th>
<th>3-year-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comprehension</strong></td>
<td>Inconsistent</td>
<td>Good</td>
</tr>
<tr>
<td><em>big/little, loud/quiet, dark/light</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Visual matching</strong></td>
<td></td>
<td>Inconsistent</td>
</tr>
<tr>
<td><em>big/little to dark/light</em></td>
<td><em>Big=dark</em></td>
<td><em>Big=loud</em></td>
</tr>
<tr>
<td><strong>Visual matching</strong></td>
<td>Inconsistent</td>
<td></td>
</tr>
<tr>
<td><em>big/little to loud/quiet</em></td>
<td></td>
<td>Little=quiet</td>
</tr>
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Non-synaesthetes: vowel sound/shape

- May influence evolution/development of language
  - “round”
  - “spikey”

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

- Can guess meanings of words in foreign languages

Ramachandran & Hubbard, 2001
Sean Day
Berlin, 1964