Sensitive periods in brain development
and their relation to education

Michael S. C. Thomas
Director, CEN

21 October 2014
Does the brain’s plasticity reduce with age?

• World Bank:
  – “Adult literacy is an important route to escape poverty in developing countries. But literacy programs aren’t that successful. Are there any sensitive periods in reading acquisition that would hinder adult learners? How could they be overcome?”
The Function linking Plasticity and Age

The graph shows the relationship between brain plasticity and age. Initially, brain plasticity increases with age, reaching a peak around the age of 5 years. After this peak, brain plasticity decreases steadily with age, reaching a plateau in older adults. The x-axis represents age, while the y-axis represents brain plasticity.
The Function linking Plasticity and Age
The Function linking Plasticity and Age

![Graph showing the function linking plasticity and age.](image-url)
The Function linking Plasticity and Age
Synaptic density in prefrontal cortex (middle frontal gyrus)

Huttenlocher (2001)
Feinberg et al. (1990)

Data standardised to the value at 30 years of age.

- Dotted line: Synaptic density squared
- Solid line: Delta wave amplitude (EEG)
- Dashed line: Cortical metabolic rate
No single ‘plasticity’?

Huttenlocher (2001)
Diverse behavioural data on sensitive periods

• Skill acquisition
  – got to start early for expertise
  – videogame playing
  – musical instruments

• Age of acquisition effects
  – early acquired vocabulary most robust

• Acquisition of a second language
  – e.g., non-native phonemes; immersion vs. interleaving

• Somatosensory and motor plasticity
  – e.g., violinists and acquired paralysis; phantom limbs

• Rehabilitation of limb paralysis after stroke

• Recovery of cognitive abilities after brain damage at different ages
  – e.g., language

• Deprivation
  – e.g., of language input, of sensory input, amblyopia

HOW MANY DIFFERENT MECHANISMS?
Takesian & Hensch (2013)

Implications for high-level cognition and education?

• Takesian & Hensch (2013):
  
  “While strict limitations on plasticity may be evident in primary sensory areas, they gradually become less rigid in higher cognitive domains ... the cellular and molecular constraints that are present at earlier stages [in the hierarchy] seem to be loosened or absent.”
Arguments for early intervention in education

• Economist James Heckman and colleagues

• Invest in early intervention to help disadvantaged children

There is compelling evidence of critical and sensitive periods in development... Different types of abilities appear to be manipulable at different ages. IQ scores become stable by age 10 or so, suggesting a sensitive period for their formation below age 10.
Different profiles of plasticity for different abilities

**Earlier drop in plasticity**

- Perceptual and motor skills
- Socio-emotional skills

Sensitive periods are more associated with socio-emotional, and perceptual and motor skills

**Later drop in plasticity**

- Executive functions
- Planning and decision making

Still plastic and developing into adolescence / young adulthood
Intervene early

= Start education early
A hierarchy of systems

Sensitive periods here >>>

Education relevant behaviours represent the interaction of many brain areas

<<< Sensitive periods here
Thomas & Knowland (2009)

– ‘An educational curriculum would be optimised if the age at which each academic subject or skill was taught coincided with the period of maximum plasticity for the brain systems involved’

– But ...
  • Age may not be the same if experience affects plasticity
  • High-level skills integrate across many systems with potentially different sensitive periods
Sensitive periods and education

• Late learned complex behaviours may be restricted by a reduction in perceptual / motor plasticity
• Learn these skills early for best ultimate proficiency
  – Learning multiple languages
  – Musician
  – Gymnast
## A change in learning style with age

<table>
<thead>
<tr>
<th>Child Learner</th>
<th>Adult learner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration</td>
<td>Intense training</td>
</tr>
<tr>
<td>Many tasks at once</td>
<td>Cease interfering tasks</td>
</tr>
<tr>
<td>Natural exposure to task</td>
<td>Exaggerate key dimensions of task</td>
</tr>
<tr>
<td>Fewer cognitive resources required</td>
<td>More cognitive resources required</td>
</tr>
<tr>
<td><strong>Attention</strong></td>
<td><strong>Attention + motivation</strong></td>
</tr>
<tr>
<td>Implicit learning, extract trends from lots of data</td>
<td>Use of strategies, rely on explicit rules (sensitive to feedback)</td>
</tr>
<tr>
<td>(less sensitive to feedback)</td>
<td></td>
</tr>
<tr>
<td>Social context enhances learning</td>
<td>Social context enhances learning</td>
</tr>
</tbody>
</table>

Adolescence is midway between the two

Thomas (2012)
Sensitive periods and education: ever too early to learn?

• **Sequence** is more important than **timing**, since more abstract / complex skills are built on a foundation of simpler ones

• **Compare best age to learn:**
  – (1) a foreign language
  – (2) the philosophy of Descartes

• **Skills related to the control of behaviour may**
  – (a) depend on later developing brain regions
  – (b) may only be relevant in later years (e.g., self-regulation, risk-taking)
Conclusions

- Education: Are there sensitive periods after which children’s learning abilities decline?
  - Yes for perceptual skills
    - Get visual / auditory problems fixed early
  - No for abilities relevant to educational curriculum
    - It’s never too late but all things being equal earlier is better (linear decline in the ultimate level of proficiency that can be achieved)
Conclusions

• Present:
  – No such thing as the brain’s plasticity
    • A range of phenomena
    • A range of mechanisms
  – Hierarchy of systems, most plastic at the top
  – Education targets top
    • Relevant sensori-motor systems need to be okay
    • Socio-emotional development needs to be okay

• Future
  – Individual differences in plasticity and IQ?
  – Removing the brakes on plasticity: can plasticity be enhanced?
    • Interfere with stability-plasticity trade-off at your peril?
    • Direct brain stimulation as example of sci-fi future?
  – When functional plasticity reduces, mechanisms responsible will determine intervention to improve behaviour
Can you supercharge your brain by zapping it with electricity? US Military tech being used by hackers to try and boost their brainpower

- Claims applying small amount of electricity could take away pain, help memory and improve attention
- Hackers have created their own $25 hardware to administer shocks

By MARK PRIGG

Applying mild electrical currents to your head could take away pain, help memory and improve attention, it has been claimed.

The technique, called transcranial direct-current stimulation (TDCS) has led to an explosion in hackers attempting to try the technique for themselves.

It has proved so successful even the US military has funded work into it.

This $350 headset can increase the plasticity of your brain and make the synapses fire faster.
Thanks for your attention!

• Acknowledgements
  – Victoria Knowland
  – Mark Johnson
  – Annette Karmiloff-Smith
  – Cathy Price
  – Helen Abadzi
  – Fiona Richardson
  – Neil Forrester
  – Funders: MRC, ESRC, Leverhulme
Knowland & Thomas (2014)

**Neurobiological principles of adult learning:**
1. Practice is crucial to achieve automaticity over competency
2. Motivation and attention to stimuli necessary. Feedback may be particularly important for older adults
3. Learning from a live tutor and actively engaging with materials more important for adults than for children
4. Order in which elements of a skill are taught is important consideration in curriculum development: fundamental skills support higher abilities
5. The learning environment should be as free from noise as possible
6. When learning a new distinction, materials should initially exaggerate relevant perceptual features. Combine with intermittent practice
7. Get a good night’s sleep to consolidate learning

**Questions requiring more research:**
- Can adults achieve the same level of automaticity as children?
  And if so, under what conditions?
- Are there low-level skills which limit complex skill acquisition? Examples: literacy, in adulthood?
- Can training attention control result in more effective and efficient learning across domains in older adults?

1. Large perceptual span
2. Attend to fine perceptual details to discriminate letters while ignoring gross differences (font, handwriting style)
3. Fine rapid control of eye movements
4. Rapid speed of visual processing
Can plasticity be enhanced?

- Behavioural techniques to optimise learning in humans
  - Properties of training (difficulty, motivation, feedback)
  - Generality of effects
    - mostly specific
    - general improvement from action video games, musical training, athletic training, aerobics, meditation

- Molecular studies of learning in animals
  - ‘Brakes’ on plasticity
    - Structural (myelination, local connectivity changes)
    - Functional (balance of excitation vs. inhibition)

Bavelier and colleagues (2008, 2010)