Evolution of the visual cortex

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Brain evolution

- The nervous system changes mainly by adding to previously existing structures.
- Old “unused” structures may become reduced, but rarely disappear altogether.
Are the cortical maps in smaller species merely "shrunken" versions of those in larger species?

Different areas do not scale isometrically across primate species.
Different areas do not scale isometrically across primate species.

There are additional areas between V2 and MT in humans, as compared with monkeys.
DEFINITION OF THE BOUNDARIES OF CORTICAL AREAS

Myelination of different cortical areas, seen in a tangential section of marmoset brain-UNSTAINED.

IMPORTANT

- The region between V1 and MT is where the major expansion of visual cortex has occurred in primate evolution.
- This “new cortex” lacks sharp architectural transitions, and contains retinotopic maps that are more variable and complex.
THE MOLECULAR ANCHORS HYPOTHESIS

1. The borders of V1 and MT are pre-specified by molecular markers. The topographic maps in these areas develop initially.

2. Other maps develop in a timed gradient. These maps are constrained by the need to maintain congruent borders with pre-existing areas.

Understanding brain evolution (focus on primates)

- To what extent can one extrapolate from animal models to humans?
  - Conserved characters, likely to have appeared early in the evolution of a taxon.
  - Characters that are unique to a certain taxon.
  - Characters that change in predictable ways as a function of brain size or habits.
Finlay and colleagues: “Late equals large”

“Which structure grows biggest is largely predicted by a conserved order of neurogenesis that can be derived from the basic axial structure of the developing brain”.

Hierarchical maturation of visual cortex

- Primary areas develop first
- High-order association areas develop last
The configuration of cortical areas changes predictably as a function of brain size.

- The smaller the primate, the larger is the proportion of the cortex taken up by the primary sensory cortices.

Should corticocortical connections also change as a function of brain size?

- J.L. Ringo (1991) (functional argument)
  - “Larger brains, being necessarily limited in allowable interconnectedness, may tend to show more specialization”.
  - Predicts more “shortcuts” in hierarchical processing in smaller animals.
Should corticocortical connections also change as a function of brain size?

- **Example:** greater separation between cortical networks in the two hemispheres, as the corpus callosum cannot “keep pace” with the increase in the area of the cortex (Rilling and Insell, 1999).

![Graph showing relationship between corpus callosum area and neocortex surface area](image)

Connections of area MT in the marmoset

- Comparing small and large animals one would expect to see that the **same cortical area** is interconnected with a larger variety of areas in a small primate, than in a large primate.

- The brain of the marmoset is 12 times smaller than the macaque brain (macaque brain is 15 times smaller than the human brain).

- A same cortical area should receive a richer set of afferent connections in the marmoset than in larger primates.
• We have studied the frontal affernts of 6 extrastriate areas in marmosets.

• Each of these areas received a more complex pattern of frontal afferents, in comparison with the macaque or Cebus monkey.
Should corticocortical connections also change as a function of brain size?

- G. F. Striedter, after Deacon, 1990 (developmental argument)

In brain evolution, large means well-connected - “Deacon’s law”

MT and the primary sensory areas are proportionately much larger in small primates than in large primates

<table>
<thead>
<tr>
<th>Species</th>
<th>Area of MT (mm$^2$)</th>
<th>Total area of cortex (mm$^2$)</th>
<th>Fraction MT/total cortex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callithrix jacchus</td>
<td>13</td>
<td>1,142</td>
<td>1.14%</td>
</tr>
<tr>
<td>Cebus apella</td>
<td>68</td>
<td>14,736</td>
<td>0.46%</td>
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<tr>
<td>Macaca fascicularis</td>
<td>74</td>
<td>14,056</td>
<td>0.53%</td>
</tr>
</tbody>
</table>

- Measurement of graphic reconstructions illustrated in Rosa and Tweedale (2005), Rosa et al. (1993), and Lewis and Van Essen (2000)
The data uphold the predictions of “Deacon’s law”: Areas that become enlarged in evolution/development command a larger proportion of the afferents to MT.

Possible implications for human brain

Greater degree of separation between areas- fewer “shortcuts”

Larger body and brain

Longer brain development (more cell divisions in cortex)

Different layout of cortical areas (e.g. V1, MT relatively small)

Different mix of afferent connections in comparison with non-human primates (e.g. less emphasis on the direct V1-MT connection, more afferents from lateral extrastriate cortex)
Possible implications for human brain

• “The idea that enlarged isocortex could be a "spandrel," a by-product of structural constraints later adapted for various behaviors, contrasts with approaches to selection of particular brain regions for cognitively advanced uses, as is commonly assumed in the case of hominid brain evolution".