Conclusion:
The window of biological opportunity when physical training is most efficient and its effects most easily retained is not fully exploited in our sports programs.

What is wrong with drawing this conclusion from the growth chart?

The pediatrician is drawing a conclusion about physical function, based only upon data that tells about gross structural change.

What other kind of data do we need to arrive at this conclusion?

We need data on specific structure-function relationships.
Synaptic Density and Glucose Metabolism (visual cortex)

Redrawn from P. Huttenlocher 1987
Conclusions:

“Thus, it is now believed by many (including this author) that the biological “window of opportunity” when learning is efficient and easily retained is perhaps not fully exploited by our educational system.” (H. Chugani, Preventive Medicine 27:184-88, 1998)

Wayne State neurobiologist Harold Chugani points out that the school-age brain almost “glows” with energy consumption, burning a 225 percent of the adult levels of glucose. The brain learns fastest and easiest during the school years. (E. Jensen, Teaching with the Brain in Mind, p.32)
What is wrong with drawing this conclusion from the data on changes in synaptic density and brain metabolism?

The pediatrician is drawing a conclusion about mental function, based only upon data that tells about gross changes in brain structure.

What other kind of data do we need to arrive at this conclusion?

We need data on specific structure-function relationships.
Delayed Non-Match to Sample
Synapses and Learning: Humans

Training to Criterion

Delays Tolerated

From Huttenlocher 1987, Diamond 1990, Overman 1990
Open Field Navigation Task

Goal

Start

61 m.
Learning an Open Field Navigation Task

H.T. Chugani; Overman et al.
• No brain science mentioned or cited

• Cites two neuroscientific studies (Shaywitz, 1996, Shaywitz et al. 1998)
  • Finding anomalous brain systems says little about change, remediation, response to treatment

• Six page appendix, “Cognition and Brain Science”
  • Dismisses “brain-based” claims about lateralization, enriched environments, and critical periods
  • Promise of cognitive neuroscientific research on dyslexia (Shaywitz, Tallal, Merzenich)

• One ten-page chapter
  • Learning is encoded by structural changes in the brain
  • No practical benefit to educators at this time
  • Brain scientists should think critically about how research is presented to educators
Brain development during childhood and adolescence: a longitudinal MRI study

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Pediatric neuroimaging studies\textsuperscript{4-5}, up to now exclusively cross sectional, identify linear decreases in cortical gray matter and increases in white matter across ages 4 to 20. In this large-scale longitudinal pediatric neuroimaging study, we confirmed linear increases in white matter, but demonstrated nonlinear changes in cortical gray matter, with a preadolescent increase followed by a postadolescent decrease. These changes in cortical gray matter were regionally specific, with developmental curves for the frontal and parietal lobe peaking at about age 12 and for the temporal lobe at about age 16, whereas cortical gray matter continued to increase in the occipital lobe through age 20.
If the increase is related to a second wave of overproduction of synapses, it may herald a critical stage of development when the environment or activities of the teenager may guide selective synapse elimination during adolescence. (Giedd et al., 1999)

New imaging studies are revealing – for the first time – patterns of brain development that extend into the teenage years. Although scientists don’t know yet what accounts for the observed changes, they may parallel a pruning process that occurs early in life that appears to follow the principle of “use-it-or-lose-it:” neural connections, or synapses, that get exercised are retained, while those that don’t are lost. At least, this what studies of animals developing visual systems suggest. (NIMH, Office of Communications and Public Liason)
…because now we're beginning to learn that the brain goes through yet another, and equally critical, growth spurt during the early teenage years. Though the research is still preliminary, scientists now believe that this is the time when all the hard-wiring of the brain takes place, when a teenager's intellectual, emotional and physical capacities are developed for a lifetime.

“Our best guess is that this process is guided by the use-it-or-lose-it principle. So those cells and connections that the teenager is using will survive and flourish. Those cells and connections that are not being used will wither and die. … which is why we feel that if children are using their brain at this point for academics or sports or music or video games that is what their brain will be hardwired or optimized for.” (Dr. Jay Giedd, *Morning Edition, May 2, 2000*)
I heard this incredible piece on NPR this morning the abstract for which I will reproduce below. This has unbelievable developmental implications -- helps explain why junior high school kids don't learn anything! If the pruning of the brain actually happens twice, this also helps explain the incredible leap in learning rates of adolescents (once the pruning begins, not during the explosion of cell growth).
Studies of the plasticity of the visual cortex during the critical period of postnatal development are particularly germane in light of recent controversies about the importance of early childhood experience in determining cortical competency in adults. These controversies—which have profound implications for early childhood education, parenting, and child care (5)—have been characterized more by polemics than by solid neuroscience research. The visual cortex represents the best model system that we have for understanding how sensory stimulation of the early brain influences brain circuitry and function throughout life. Its study should increase our knowledge of the ways in which early sensory inputs determine the long-term capabilities of the brain.

Which field of brain research is concerned with investigating structure-function relationships?

Cognitive neuroscience attempts to determine how neural structures implement mental functions.

How do cognitive neuroscientists make structure-function inferences?

They conduct brain imaging/recording experiments where the experimental tasks are based on prior analyses of how component mental functions contribute to the task.
Which field of research is concerned with analyzing tasks and behaviors into their component mental functions?

Cognitive psychology

How do cognitive psychologists do their work?

They conduct behavioral experiments and computational modeling to develop functional models showing how component mental functions account for specific skills and behavior.
What are the implications of this approach for cognitive neuroscience?

• Brain imaging studies are as good as the cognitive analyses or models underlying the experimental task.
• Cognitive analyses are essential for appropriate interpretation of brain imaging experiments.
• Given this current conceptual primacy, cognitive neuroscience can make function $\rightarrow$ structure inferences about localization, but not structure $\rightarrow$ function inferences.
Imaging: A Window on the Brain

Counting backward from 50 by 3s

<table>
<thead>
<tr>
<th>Task</th>
<th>Stresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mentally name letters</td>
<td>Control condition</td>
</tr>
<tr>
<td>Name target digit</td>
<td>Visual &amp; verbal systems/representations</td>
</tr>
<tr>
<td>Compare target digit with standard, mentally say “larger”, “smaller”</td>
<td>Magnitude system/representation.</td>
</tr>
<tr>
<td>Multiply target digit by 3, mentally name</td>
<td>Verbal system/representation</td>
</tr>
<tr>
<td>Subtract target digit from 11, mentally name</td>
<td>Magnitude representation (relative to multiplication)</td>
</tr>
</tbody>
</table>
Number Tasks: Activated Brain Areas

Chochon et al., Journal of Cognitive Neuroscience 11:6, pp. 617–630
Individual variation in number processing

Chochon et al., Journal of Cognitive Neuroscience 11:6, pp. 617–630
Functional disruption in the organization of the brain for reading in dyslexia

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Previous efforts using functional imaging methods to examine brain organization in dyslexia have been inconclusive largely, we think, because the experimental tasks tapped the several aspects of the reading process in somewhat unsystematic ways. Our aim therefore was to develop a set of hierarchically structured tasks that control the kind of language-relevant coding required, including especially the demand on phonologic analysis, and then to compare the performance and brain activation patterns (as measured by functional MRI) of dyslexic (DYS) and nonimpaired (NI) readers.
Shaywitz et al. 1998 Experimental Task

<table>
<thead>
<tr>
<th>Phonological Task Hierarchy</th>
<th>Dyslexics (% Errors)</th>
<th>Normals (% Errors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line orientation (/&gt; vs. &lt;)</td>
<td>5.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Letter case (Bb vs. bB)</td>
<td>7.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Single letter rhyme (T vs. V)</td>
<td>11.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Non-word rhyme (leat vs. jete)</td>
<td>31.5</td>
<td>9.3</td>
</tr>
<tr>
<td>Semantic category (rice vs. corn)</td>
<td>13.8</td>
<td>4.6</td>
</tr>
</tbody>
</table>

*Significant difference* b/n dyslexics and normals
Fig. 2. Composite activation maps in DYS and NI readers for the C and NWR judgment tasks. As shown, DYS and NI readers differ in the degree of activation produced in different brain regions during phonologic (NWR) compared with orthographic (C) coding. DYS readers demonstrate a pattern of relative overactivation anteriorly in IFG in contrast to relative underactivation posteriorly, in STG and the angular gyrus. Composite maps (with z-axis Talairach position) are shown for the left anterior region (IFG, z = 33) and two regions in the left posterior system [post STG (STG, z = 12) and the angular gyrus (ANG, z = 23)]. Composite maps are based on brain activations representing C and NWR. The median t value was obtained for each pixel in each of the Talairach-transformed images of the 29 DYS and 32 NI readers, respectively. Those t values greater than 0.2 were cluster-filtered (cluster size = 3) and overlaid on composite anatomic images that were obtained by adding Talairach-transformed anatomical images from the two groups. The cluster criterion used in this composite differs from that used in the statistical analysis; when combining multiple activation maps from different subjects, it is necessary to change the threshold and cluster criterion to compensate for imprecise overlap of activation regions between subjects.
What value do these function → structure inferences have for educators?

What implications do these function → structure inferences have for educational practice?
Instructional Implications: None

• Numeracy
  – Numeracy requires integrating three representations of number
  – Learning problems arise from inadequate integration of these representations
  – Training studies show learning problems remediable when representations and their integration are taught explicitly (Resnick, Case & Griffin)

• Early Reading
  – Word recognition requires integrating linguistic representations
  – Dyslexia can arise from inadequate integration of orthographic/phonological representations
  – Training studies show explicit integrative instruction is beneficial (Bradley & Bryant 1983, NRP, NRC)
Are functional explanations all we need as a basis for an applied science of learning?

- Currently, such explanations are the best we have
- Practically, these explanations provide a vast, largely untapped resource for improving instruction.
- Functional explanations are fundamental both for an applied science of learning and for advances in cognitive neuroscience.
- Imaging data adds nothing
How could brain science contribute to an applied science of learning?

- Cognitive neuroscience is the most likely place to look for future educationally relevant insights.
- Cognitive neuroscience is supported by two legs: cognitive science and basic neuroscience.
- Basic neuroscience findings that support \textit{structure} $\rightarrow$ \textit{function} inferences might eventually place independent biological constraints on cognitive theories and analyses.
What questions must cognitive neuroscience address in order to draw structure → inferences?

• *How* (not just *where*) do neural structures implement mental functions?
• How do brain structures – synapses, neural networks – code and transmit information?
• What are the metabolic and physiological sources of the signals measured with various imaging technologies?
• What is the appropriate model for studying brain development and learning?