Lead and Learning: Impacts of Low Levels of Lead on Children’s Ability to Learn

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Objectives

• To understand how and why children are more susceptible to environmental exposures, especially lead, than adults

• To understand sources of lead for children in both indoor and outdoor environments

• To become familiar with impacts of lead on children’s learning, especially as they affect
  – child’s ability to master core concepts of math and reading,
  – behaviors in school that may also impact learning
Background

Children’s Health
A Child’s Environment Is All Around Them

- Eating
- Drinking
- Breathing
- Touching
Children’s Environments

Outdoor contaminants impact indoor environments

- Home: 61%-76%
- School: 12%-33%
- Childcare: 6%-12%
- Outdoors: 6%-12%
Children Are Not Little Adults

Rapid Growth and Development

Children’s Increased Vulnerability
Stages of Prenatal and Postnatal Organ Development

**Early Prenatal**
- Central nervous system (3wks - 20 years)
- Ear (4-20 wks)
- Kidneys (4-40 wks)
- Heart (3-8)
- Limbs (4-8wks)
- Skeleton (1-12 wks)

**Mid-Prenatal**
- Immune system (8-40 wks; competence & memory birth-10yrs)

**Late Prenatal**
- Lungs (3-40 wks; alveoli birth-10yrs)
- Reproductive system (7-40wks; maturation in puberty)

**Postnatal**
- Birth
- – 25 years

Neuronal Growth in Early Childhood

Newborn 3-month old 2 year old
Children Are Not Little Adults

Rapid Growth and Development

Differences in How Their Bodies Work

Children’s Increased Vulnerability
Exposure Differences: Physiology

Increased Exposures Relative to Adults

- Pound for pound, kids
  - breathe more air than adults
  - drink more water than adults
  - eat more food than adults
  - have increased surface area to body mass ratio relative to adults

- May also have different metabolism routes, speeds due to enzyme availability or activity
Fluid Consumption, L per Kg Body Weight per Day

Intake 7X Greater than Adults

<table>
<thead>
<tr>
<th>AGE</th>
<th>1 - 3 months</th>
<th>6-12 months</th>
<th>2 - 3 years</th>
<th>11 - 16 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liters per Kg Body Weight Per Day</td>
<td>0.30</td>
<td>0.25</td>
<td>0.15</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Adult Consumption
Lead Absorption in Children

• Ingested lead absorption rates
  – 10% in adults
  – 50% in children

• Children who are deficient in certain nutrients absorb even more of the lead they ingest
  – Iron
  – Calcium
  – Zinc
  – Vitamin C
Children Are Not Little Adults

Rapid Growth and Development

Differences in How Their Bodies Work

Differences in the Ways They Act

Children’s Increased Vulnerability
Exposure Differences: Behaviors

Increased Exposures Relative to Adults

• Closer to the ground
• Diet and eating habits differ
  – Newborns - breast milk or formula
  – Infants / Toddlers - more fruit and milk products
  – “Fussy Eaters” abound
  – “Grazing” is common

• Little control over the environment where they spend time
Exposure Differences: Behaviors

Increased Exposures Relative to Adults

• Engage in more potentially high-risk behavior
  – Increased hand contact with “stuff”
  – Increased mouthing behaviors
  – More time spent on floor
  – More time spent outdoors
The Significance of Small Effects:
Effects of a Small Shift in IQ Distribution in a Population of 300M

- 6.9 million "developmental disability"
- 6.9 million "gifted"
The Significance of Small Effects: 5 Point Decrease in Mean IQ

Mean 95

57% INCREASE

9.4 million "developmental disability"

2.4 million "gifted"
### Environmentally Attributed Childhood Healthcare Costs in US

<table>
<thead>
<tr>
<th>Illness</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Poisoning</td>
<td>$50.9 Billion</td>
</tr>
<tr>
<td>Asthma</td>
<td>$2.2 Billion</td>
</tr>
<tr>
<td>Neurobehavioral Disorders</td>
<td>$23.4 Billion</td>
</tr>
</tbody>
</table>

$76.6 Billion

Represents ~ 3% Total US Healthcare Costs

Background

Lead
Where Can the Lead Be Coming From?

- Air
- Water
- Soil
- Toys
- Jewelry

Never use HOT WATER for cooking or drinking!

- LEAD PAINT DUST

Houses built before 1978
Where Can the Lead Be Coming From?

• Air
• Water
• Soil
• Toys
• Jewelry

LEAD PAINT DUST

Houses built before 1978

Never use HOT WATER for cooking or drinking!
Lifelong Health Effects of Lead

- Damage to the brain and nervous system

- Behavior and learning problems (such as)
  - Hyperactivity
  - Poor impulse control
  - Violence
  - Lower IQ

- Delayed growth

- Other problems
  - Hearing
  - Headaches

Effects of early exposure to lead are not reversible
Other Health Effects of Lead

- Difficulties during pregnancy
- Other reproductive problems (in both men and women)
- High blood pressure
- Digestive problems
- Nerve disorders
- Memory and concentration problems
- Muscle and joint pain
- Cataracts
Decline in Children’s Blood Lead Levels due to Regulation

- Lead-Based Paint Poisoning Prevention Act
- Begin Phase-Out of Leaded Gasoline
- Residential Lead Paint ban (1978)
- Lead in Plumbing Ban (1986)
- Lead-Based Paint Hazard Reduction Act (1992)


Blood Lead Levels (µg/dL):
- 20
- 18
- 16
- 14
- 12
- 10
- 8
- 6
- 4
- 2
- 0
No safe blood lead level in children has been identified!
Elevated Blood Lead Levels

• No safe level of exposure to lead

• 5 μg/dL of lead in blood used as reference value
  – 2.5% of children nationally above reference value
  – Used for prioritizing resources
  – Not health-based or “protective”

• Children under 6 years and pregnant women most vulnerable
The Ripple Effects of Childhood Lead Poisoning

Source: LeadSafe Illinois, Loyola University Chicago Civitas ChildLaw Center and Policy Institute
Percent of Pre-1980 Housing Units, By County

Source: Indiana State Department of Health
Lead & Healthy Homes Program
2013 Surveillance Report
Lead Poisoning Rate, > 5 μg/dL
US and IN 2010 - 2013

Source: CDC data, www.cdc.gov/nceh/lead
Lead and Learning
Lead Affects Brain Development, Organization, Maturation and Plasticity

The developing brain is especially sensitive to toxins (such as lead) that can disrupt the finely tuned sequence of events that lead to a mature, normally functioning nervous system, resulting in significant functional problems.

Source: Jay S. Schneider, Ph.D. Thomas Jefferson University, Philadelphia, PA
No “Behavioral Signature” for Lead Poisoning

• Different brain regions mature at different times: different functions are susceptible to disruption according to timing, amount, and duration of the insult

• Differential effects of Pb poisoning - different parts of the brain do different things; different parts of the brain are affected by lead in different people.

Source: Jay S. Schneider, Ph.D. Thomas Jefferson University, Philadelphia, PA
### Summary of Neurological Health Effects of Low-level Lead

<table>
<thead>
<tr>
<th>Health Effect</th>
<th>Population or Exposure Window</th>
<th>NTP Conclusion</th>
<th>Blood Pb Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cognitive Function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academic achievement</td>
<td>Prenatal</td>
<td>Inadequate</td>
<td>No studies located</td>
</tr>
<tr>
<td>Children</td>
<td>Sufficient</td>
<td>Yes, &lt;5 µg/dL</td>
<td></td>
</tr>
<tr>
<td><strong>IQ</strong></td>
<td>Prenatal</td>
<td>Limited</td>
<td>Yes, &lt;10 µg/dL</td>
</tr>
<tr>
<td>Children</td>
<td>Sufficient</td>
<td>Yes, &lt;5 µg/dL</td>
<td></td>
</tr>
<tr>
<td>Other general and specific measures</td>
<td>Prenatal</td>
<td>Limited</td>
<td>Yes, &lt;5 µg/dL</td>
</tr>
<tr>
<td>Children</td>
<td>Sufficient</td>
<td>Yes, &lt;5 µg/dL</td>
<td></td>
</tr>
<tr>
<td>Older adults</td>
<td>Limited</td>
<td>Yes, &lt;10 µg/dL</td>
<td></td>
</tr>
<tr>
<td><strong>Behavior</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention-related behaviors</td>
<td>Prenatal</td>
<td>Limited</td>
<td>Yes, &lt;10 µg/dL</td>
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<tr>
<td>Children</td>
<td>Sufficient</td>
<td>Yes, &lt;5 µg/dL</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>Inadequate</td>
<td>No studies located</td>
<td></td>
</tr>
<tr>
<td>Behavioral problems</td>
<td>Prenatal</td>
<td>Limited</td>
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</tr>
<tr>
<td><strong>Sensory Function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auditory</td>
<td>Prenatal</td>
<td>Limited</td>
<td>Yes, &lt;10 µg/dL</td>
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<tr>
<td>Children</td>
<td>Sufficient</td>
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<tr>
<td>Adults</td>
<td>Limited</td>
<td>Yes, &lt;10 µg/dL</td>
<td></td>
</tr>
<tr>
<td>Visual</td>
<td>Prenatal</td>
<td>Inadequate</td>
<td>Yes, &lt;10 µg/dL</td>
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<tr>
<td>Children</td>
<td>Inadequate</td>
<td>Yes, &lt;10 µg/dL</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>Inadequate</td>
<td>No studies located</td>
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</table>

Source: National Toxicology Program, 2012
# Studies on Lead and Educational Outcomes

<table>
<thead>
<tr>
<th>Blood Lead Levels</th>
<th>Educational Impact</th>
<th>Size of Study</th>
<th>Location of Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 3 μg/dL</td>
<td>Decreased end of grade test scores</td>
<td>More than 57,000 children</td>
<td>North Carolina (Miranda et al. 2009)¹</td>
</tr>
<tr>
<td>4 μg/dL at 3 years of age</td>
<td>Increased likelihood learning disabled classification in elementary school</td>
<td>More than 57,000 children</td>
<td>North Carolina (Miranda et al. 2009)¹</td>
</tr>
<tr>
<td></td>
<td>Poorer performance on tests</td>
<td>35,000 children</td>
<td>Connecticut (Miranda et al. 2011)</td>
</tr>
<tr>
<td>5 μg/dL</td>
<td>30% more likely to fail third grade reading and math tests</td>
<td>More than 48,000 children</td>
<td>Chicago (Evens et al. unpublished data)</td>
</tr>
<tr>
<td></td>
<td>More likely to be non-proficient in math, science, and reading</td>
<td>21,000 children</td>
<td>Detroit (Zhang et al. 2013)</td>
</tr>
<tr>
<td>5-9 μg/dL</td>
<td>Scored 4.5 points lower on reading readiness tests</td>
<td>3,406 children</td>
<td>Rhode Island (McLaine et al. 2013)</td>
</tr>
<tr>
<td>≥10 μg/dL</td>
<td>Scored 10.1 points lower on reading readiness tests</td>
<td>3,406 children</td>
<td>Rhode Island (McLaine et al. 2013)</td>
</tr>
<tr>
<td>10 and 19 μg/dL</td>
<td>Significantly lower academic performance test scores in 4th grade</td>
<td>More than 3,000 children</td>
<td>Milwaukee (Amato et al. 2012)</td>
</tr>
<tr>
<td>≥ 25 μg/dL</td>
<td>$0.5 million in excess annual special education and juvenile justice costs</td>
<td>279 children</td>
<td>Mahoning County, Ohio (Stefanak et al. 2005)</td>
</tr>
</tbody>
</table>

Early Meta Analyses (Studies of Studies)  
Suggested Lead Impacts on Learning

• Needleman & Gatsonis (1990)
  – 12 studies, both Prospective and cross-sectional
  – 7 blood, 5 tooth
  – Conclusion - 2 to 6 IQ point loss per 10 μg/dL

• Schwartz (1994)
  – 8 studies, both Prospective and cross-sectional
  – Blood lead only (to age 3 years), 6.5 to 23 μg/dL
  – Conclusions - 2.6 IQ point loss, 10 to 20 μg/dL, with possible greater effect at lower levels
Lead-Associated Reading Deficits in US Children

Source: Lanphear et al, Public Health Reports, 2000, 115:521-529
Association of IQ and Children’s Blood Lead Levels at 60 Months of Age

Source: Canfield et al, New England Journal of Medicine, 2003, 348: 1517-1526
Percent of 4th Graders Failing End of Grade Reading Test, By Blood Lead Level, 2000-2004, North Carolina

Preschool Blood Lead vs Mental Retardation Prevalence (with 12 year lag) in US

Source: Nevin, Environmental Research, 2009
Preschool Blood Lead vs SAT Math and Verbal scores (with 17-year lag) in US

Source: Nevin, Environmental Research, 2009
Mean Blood Lead Levels, By Michigan Educational Assessment Program Scores, Grades 3, 5, 8
Detroit Public Schools, MI, 2008–2010

Source: Zhang et al, American Journal of Public Health, March 2013, 103(3), e72-e77
BLL Predicts Probability of Scoring “Less than Proficient”
MI Educational Assessment Program, Detroit Public Schools, 2008-2010

Source: Zhang et al, American Journal of Public Health, March 2013, 103(3), e72-e77
Failure in Reading & Math Due to BLL

- Large study (n=58,650), Chicago Public Schools, children who had pre-school blood lead level (BLL) and 3rd grade state achievement test results
- Adjusted for other predictors of school performance
- For a 5 μg/dL increase in BLL, the risk of failing
  - Increased by 32% for reading
  - Increased by 32% for math
- Effect of lead on reading was non-linear with steeper failure rates at lower BLLs
- Estimated that 13% of reading failure and 14.8% of math failure attributed to BLL of 5 to 9 μg/dL in Chicago school children

ADHD

- Disruptive behavior disorder characterized by symptoms of inattention and/or hyperactivity-impulsivity

- Children with ADHD generally have trouble with certain skills involved in problem-solving (referred to collectively as executive function).
  - Working memory
  - Planning
  - Response inhibition
  - Cognitive flexibility

- Children with ADHD also generally have problems
  - Vigilance
  - Maintaining readiness to respond to new information

Source: America’s Children and the Environment, 3rd Edition
Increased BLL and Likelihood of ADHD

• While uncertainties remain, findings to date indicate that ADHD is caused by combinations of genetic and environmental factors.

• BLLs and parent-reported ADHD diagnosis was observed in 4,704 children 4–15 years of age:
  – Subjects with BLL >2.0 μg/dL were 4X more likely to have ADHD Dx, be on stimulant medication than those with BLL <0.8 μg/dL.

Source: Braun et al. 2006
Increased BLL & Executive Functions (EF)

- EF closely related to Attention

- Children with higher EBLs (less than 20 ug/dL with mean BLL in the range of 7 ug/dL) performed more poorly on tests of executive processes
  - working memory
  - attentional flexibility
  - planning and problem solving

Source: Canfield et al 2003 and Canfield et al 2004
Key Ways Early Care / Educational Systems Can Support Improved Outcomes for Lead-Exposed Children

• Streamlined access to developmental assessment, intervention and special education service

• Conducting a neuropsychological assessment of executive function in addition to a developmental assessment to identify cognitive and functional deficits in children with elevated BLLs.

• Consistent interpretation of provisions in IDEA and ADA that require provision of assessment and educational interventions, & mechanisms to ensure that children with a history of EBLLs receive services

• Technical advice on the implications of the connection between lead exposure and educational results for all stakeholders

Action Steps

• Practice primary prevention to keep children from being exposed to lead
  – Spread the word about lead
  – Reduce children’s exposures to lead in homes, schools, child care facilities, playgrounds, yards

• Ensure children are being tested for lead, preferably 3 times before the age of 3

• Lead Safe Work Practices in pre-1978 child-occupied spaces
  – DIY
  – Hire someone RRP-certified
Action Steps (continued)

• Ensure children who have been exposed to lead get educational support for optimal outcomes
  – Tailored
  – Relevant
  – EARLY
Region 5 Pediatric Environmental Health Specialty Unit (PEHSU) 
Great Lakes Center for Children’s Env Health

866-967-7337  312-864-5526  312-636-0081

• Part of nat’l network co-funded by EPA and ATSDR
• Serves as a Regional resource to:
  – evaluate, treat and prevent environmental illness in children
  – train pediatricians and others in environmental health issues
  – promote children’s environmental health in communities
Please feel free to contact us for more information, or to suggest ways we may be able to partner in activities that will have a positive impact on children’s health.

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