Health Effects of Air Pollution

Michael Brauer
Key pollutants for health impacts

- **Particulate Matter (PM)**
- **Ozone (O₃)**
- **Nitrogen Dioxide (NO₂)**
Air pollution and health

- Ambient air pollution (individual) **risk** is small...but large **exposed population = large population risk**
- Diseases impacted by air pollution have other causes...
- ...Air pollution as a contributing risk factor
Air pollution and health

• On **days** with worse air quality, more people die*


*out-of-hospital, >65 yrs*
Ambient Particulate Air Pollution and Daily Mortality in 652 Cities

Air pollution and health

- On **days** with worse air quality, more people die*

- In **more polluted cities**, people die earlier than in less polluted cities...

*out-of-hospital, >65 yrs

Long-term fine particulate matter exposure and non-accidental and cause-specific mortality in a large national cohort of Chinese men

10 km satellite-based estimates + surface measurements

~190,000 men > 40 years, 45 locations randomly selected from 145 DSPs

15 year follow-up

No evidence of threshold

Pappin et al., 2019; Christidis et al., 2019
Air pollution and health

• On **days** with worse air quality, more people die*

• In more polluted cities, people die earlier than in less polluted cities...

• ...and, in the **most polluted areas** of cities, there is an increased risk of dying


*out-of-hospital, >65 yrs
Traffic-related air pollution

Air pollution and health

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• In **more polluted cities**, people die earlier than in less polluted cities...

• ...and, in the **most polluted areas** of cities, there is an increased risk of dying


*out-of-hospital, >65 yrs
Air pollution reduces lung function growth in children…


…which leads to earlier than normal disability/death
Air pollution reduces lung function growth in children…


…which leads to earlier than normal disability/death
Systemic effects

Blood

- PM or constituents in the circulation
  - UFP, soluble metals
  - Organic compounds

Vasculature

- Vasoconstriction
- Endothelial dysfunction
- PM-mediated ROS
  - ↑ BP
  - ? Atherosclerosis
- Blood
  - ? ↑ Platelet aggregation

Blood

- Acute phase response
  - ↑ Activated WBCs, platelets, MPO
  - ↑ Cytokine expression/levels (↑ IL-1β, IL-6, TNF-α)
  - ↑ ET, histamine, cell microparticles, oxidized lipids; ↓ anti-oxidants

- ↑ Adipokines (PAI-1, Resistin)
- Direct actions
  - Activated or Inflamed fat

- Activated or Inflamed liver

- Vasculature
  - Endothelial cell dysfunction/vasoconstriction, ↑ ROS
  - Atherosclerosis progression/plaque vulnerability
  - ↑ Thrombogencity (e.g., tissue factor)

- Metabolism
  - Insulin resistance, dyslipidemia, impaired HDL function

- Blood
  - ↑ Coagulation, thrombosis; ↓ fibrinolysis (e.g., PAI-1)

ANS imbalance

- ↑ SNS / ↓ PSNS

ANS

- Vasconstriction
- Endothelial dysfunction
- Neural-mediated ROS
  - ↑ BP

Blood

- ↑ Platelet aggregation

Heart

- ↓ HRV
  - ↑ Heart rate
  - Arrhythmia potential
Beyond the heart and lung

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Health Effect Category and Exposure Duration</th>
<th>2009 PM ISA</th>
<th>Current Draft PM ISA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM2.5</td>
<td>Respiratory Effects—Short-term exposure</td>
<td>Likely to be a causal relationship</td>
<td>Likely to be a causal relationship</td>
</tr>
<tr>
<td></td>
<td>Respiratory Effects—Long-term exposure</td>
<td>Likely to be a causal relationship</td>
<td>Likely to be a causal relationship</td>
</tr>
<tr>
<td></td>
<td>Cardiovascular Effects—Short-term exposure</td>
<td>Causal relationship</td>
<td>Causal relationship</td>
</tr>
<tr>
<td></td>
<td>Cardiovascular Effects—Long-term exposure</td>
<td>Causal relationship</td>
<td>Causal relationship</td>
</tr>
<tr>
<td></td>
<td>Nervous System Effects—Long-term exposure</td>
<td>Not evaluated</td>
<td>Likely to be a causal relationship</td>
</tr>
<tr>
<td></td>
<td>Cancer—Long-term exposure</td>
<td>Suggestive of, but not sufficient to infer a causal relationship</td>
<td>Likely to be a causal relationship</td>
</tr>
<tr>
<td></td>
<td>Total mortality—Short-term exposure</td>
<td>Causal relationship</td>
<td>Causal relationship</td>
</tr>
<tr>
<td></td>
<td>Total mortality—Long-term exposure</td>
<td>Causal relationship</td>
<td>Causal relationship</td>
</tr>
</tbody>
</table>

WHO REVIHAAP (2013): Cardiovascular and Respiratory Mortality and Morbidity
Growing evidence for birth outcomes and childhood respiratory disease
Possible links with neurodevelopment and cognitive function, diabetes

IARC (2013): Air pollution (and PM specifically) carcinogenic (lung cancer)

USEPA
Pregnancy and Birth Outcomes: Suggestive of, but not sufficient

Health impacts of air pollution:
- shorter life
- cognitive development
- cognitive decline
- mental health
- stroke
- heart disease
- asthma
- lung cancer
- reduced lung function
- obesity
- birth defects
- low birth weight
- diabetes

Established effects
Possible effects
95% of population exposed above WHO Guideline

Brauer et al., 2012; Brauer et al., 2016; Shaddick et al. 2017. Shaddick et al., 2018.
Road injuries

~9% of all deaths

2.9 M deaths PM$_{2.5}$

1.6 M deaths Household

470 K deaths Ozone

$5 trillion/yr$ welfare losses

$225 billion/yr$ lost labour income

+ Low Birthweight/Short Gestation (added in GBD2019)

World Bank. 2016. *The cost of air pollution: strengthening the economic case for action*

[https://vizhub.healthdata.org/gbd-compare/](https://vizhub.healthdata.org/gbd-compare/)
Road injuries cost $5 trillion annually in welfare losses and $225 billion in lost labour income.

Four leading causes of death globally in 2017:
- Stroke (15%) - 440K
- Ischemic Heart Disease (33%) - 980K
- COPD (22%) - 630K
- Lower Respiratory Infections (15%) - 430K
- Lung Cancer (9%) - 270K

Other significant causes include:
- HIV/AIDS & STIs
- Respiratory infections & TB
- Enteric infections
- NTDs & malaria
- Other infectious
- Maternal & neonatal

Source: https://vizhub.healthdata.org/gbd-compare/

+ Low Birthweight/Short Gestation
Ozone Trends

Preliminary Results, GBD 2019
Demographics plays a key role

Adverse reproductive outcomes

Preliminary Results, GBD 2019
What’s missing?

Incident childhood asthma and NO\textsubscript{2}


<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>log(Odds Ratio)</th>
<th>SE</th>
<th>Weight</th>
<th>IV, Random, 95% CI</th>
<th>Odds Ratio</th>
<th>IV, Random, 95% CI</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carlsen et al. 2010 - at 7 y.o.</td>
<td>0.2253</td>
<td>0.1448</td>
<td>0.6%</td>
<td>1.25 [0.94, 1.66]</td>
<td></td>
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</tr>
<tr>
<td>Clark et al. 2010 LUR - at mean age of 4 y.o.</td>
<td>0.0489</td>
<td>0.0171</td>
<td>9.5%</td>
<td>1.05 [1.02, 1.09]</td>
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<tr>
<td>Dell et al. 2014 LUR - 5 to 9 y.o.</td>
<td>0.039</td>
<td>0.04</td>
<td>5.0%</td>
<td>1.04 [0.96, 1.12]</td>
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<tr>
<td>Deng et al. 2016 - 3 to 6 y.o.</td>
<td>0.1374</td>
<td>0.0689</td>
<td>2.4%</td>
<td>1.15 [1.00, 1.31]</td>
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<tr>
<td>Gehring et al. 2015 b - BAMSE birth to 16 y.o.</td>
<td>0.0397</td>
<td>0.0498</td>
<td>3.8%</td>
<td>1.04 [0.94, 1.15]</td>
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<tr>
<td>Gehring et al. 2015 b - PIAMA birth to 14 y.o.</td>
<td>0.0665</td>
<td>0.0246</td>
<td>7.8%</td>
<td>1.07 [1.02, 1.12]</td>
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<tr>
<td>Gehring et al. 2015b - GINI&amp;LISA North birth to 15</td>
<td>-0.0679</td>
<td>0.1235</td>
<td>0.8%</td>
<td>0.93 [0.73, 1.19]</td>
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<tr>
<td>Gehring et al. 2015b - GINI&amp;LISA South birth to 15</td>
<td>-0.0252</td>
<td>0.0602</td>
<td>2.9%</td>
<td>0.98 [0.87, 1.10]</td>
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<tr>
<td>Jerret et al. 2008 - 10 to 18 y.o.</td>
<td>0.0874</td>
<td>0.033</td>
<td>6.1%</td>
<td>1.09 [1.02, 1.16]</td>
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<tr>
<td>Kim et al. 2016 - 6 to 7 y.o.</td>
<td>-0.0214</td>
<td>0.0219</td>
<td>8.4%</td>
<td>0.98 [0.94, 1.02]</td>
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<tr>
<td>Krâmer et al. 2009 - 4 to 6 y.o.</td>
<td>0.0698</td>
<td>0.069</td>
<td>2.3%</td>
<td>1.07 [0.94, 1.23]</td>
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<tr>
<td>Liu et al. 2016 - 4 to 6 years old</td>
<td>0.0877</td>
<td>0.0215</td>
<td>8.5%</td>
<td>1.09 [1.05, 1.14]</td>
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<tr>
<td>MacIntyre et al. 2014 - CAPPS&amp;SAGE only birth to 8</td>
<td>0.1111</td>
<td>0.1268</td>
<td>0.8%</td>
<td>1.12 [0.87, 1.43]</td>
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<tr>
<td>McConnell et al. 2010 - 4th to 6th grade</td>
<td>0.0698</td>
<td>0.0281</td>
<td>7.1%</td>
<td>1.07 [1.01, 1.13]</td>
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<tr>
<td>Mölter et al. 2014 b - MAAS only birth to 8 y.o.</td>
<td>0.574</td>
<td>0.2374</td>
<td>0.2%</td>
<td>1.78 [1.11, 2.83]</td>
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</tr>
<tr>
<td>Nishimura et al. 2013 - 8 to 21 y.o.</td>
<td>0.0632</td>
<td>0.0269</td>
<td>7.3%</td>
<td>1.07 [1.01, 1.12]</td>
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</tr>
<tr>
<td>Ofstedal et al. 2009 - birth to 10 y.o.</td>
<td>-0.0359</td>
<td>0.0196</td>
<td>8.9%</td>
<td>0.96 [0.93, 1.00]</td>
<td></td>
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</tr>
<tr>
<td>Ranzi et al. 2014 - birth to 7 y.o.</td>
<td>0.0289</td>
<td>0.0701</td>
<td>2.3%</td>
<td>1.03 [0.90, 1.18]</td>
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</tr>
<tr>
<td>Shima et al. 2002 - 6 to 12 y.o.</td>
<td>0.1136</td>
<td>0.0534</td>
<td>3.5%</td>
<td>1.12 [1.01, 1.24]</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Têtreault et al. 2016 - birth to 12 y.o.</td>
<td>0.0153</td>
<td>0.0048</td>
<td>11.6%</td>
<td>1.02 [1.01, 1.03]</td>
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</tr>
</tbody>
</table>

Total (95% CI) 100.0% 1.05 [1.02, 1.07]

Heterogeneity: \( \tau^2 = 0.00; \ Chi^2 = 54.38, df = 19 (P < 0.0001); I^2 = 65\% \)

Test for overall effect: \( Z = 3.76 \) (\( P = 0.0002 \))

per 4 \( \mu g/m^3 \) NO\textsubscript{2} Decreased risk Increased risk

0.5 0.7 1 1.5 2
Ambient NO$_2$ and Pediatric Asthma

- 4.0 (1.8 - 5.2) million new pediatric asthma cases annually
- 13% (5.8 - 16%) of global incidence

Achakulwisut et al. Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: estimates from global datasets. Lancet Planetary Health DOI: (10.1016/S2542-5196(19)30046-4)
In high and low income country cities, NO₂ pollution is an important risk factor for pediatric asthma incidence.

125 major cities, % of new pediatric asthma cases attributable to NO₂:
• Range: 6% (Orlu, Nigeria) to 48% (Shanghai, China).
• Exceeded 20% in 92 cities, in high and low income countries.
• Highest in 8 cities in China, in Moscow, and Seoul.

Achakulwisut et al., 2019, Lancet Planetary Health
Traffic proximity and dementia

Non-Alzheimer’s dementia


Yuchi et al., 2019. Submitted
Autism Spectrum Disorder

Vancouver BC: 132,256 births, 1307 children (1.0%) diagnosed with ASD by age 5

<table>
<thead>
<tr>
<th>Health Outcome</th>
<th>Causality (strength of association)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asthma exacerbation</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Asthma onset</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Adults</td>
<td>Suggestive, but insufficient</td>
</tr>
<tr>
<td>Lung function decrements (children, chronic exposure)</td>
<td>Suggestive, but insufficient</td>
</tr>
<tr>
<td>Lung Cancer</td>
<td>Suggestive, but insufficient</td>
</tr>
<tr>
<td>CVD mortality (chronic and acute exposure)</td>
<td>Suggestive, but insufficient</td>
</tr>
<tr>
<td>CVD morbidity</td>
<td></td>
</tr>
<tr>
<td>MI onset</td>
<td>Suggestive, but insufficient</td>
</tr>
<tr>
<td>Atherosclerosis progression</td>
<td>Suggestive, but insufficient</td>
</tr>
<tr>
<td>Pregnancy outcomes</td>
<td>Inadequate and insufficient</td>
</tr>
<tr>
<td>Allergy</td>
<td>Inadequate and insufficient</td>
</tr>
<tr>
<td>childhood leukemia, cancer</td>
<td>Inadequate and insufficient</td>
</tr>
<tr>
<td>COPD</td>
<td>Inadequate and insufficient</td>
</tr>
</tbody>
</table>
Traffic-related air pollution: Health Impacts

Selected health outcomes:

All cause and cause-specific mortality
• Respiratory (Chronic Obstructive Pulmonary Disease, Acute Lower Respiratory Infections)
• Circulatory (Ischemic Heart Disease, Stroke)
• Diabetes
• Lung cancer

Respiratory effects
• Asthma
• Chronic Obstructive Pulmonary Disease
• Acute Lower Respiratory Infections

Cardiovascular effects
• Coronary events
• Stroke
• Hypertension
• Type 2 diabetes

Birth outcomes
• Low birth weight
• Preterm
Thank you

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