REVIEW OF EVIDENCE ON HEALTH ASPECTS OF AIR POLLUTION - REVIHAAP

MICHAL KRZYZANOWSKI, ScD, PhD

Visiting Professor, Kings College London
This presentation:

Summary of the results of the WHO – EC project “Review of evidence on health aspects of air pollution - REVIHAAP”


Plus examples from selected studies.
About REVIHAAP

• WHO project jointly financed by WHO and EC, managed by WHO/ECEH (Marie-Eve Heroux)

• Evidence review in response to 24 key policy questions from the EC

• Timing: 18 months, Sept 2011 – April 2013

• Steering Advisory Committee (8 experts, 2 meetings, multiple TCs)

• Review of evidence and drafting the answers: 29 experts

• External review: 30 experts

• Two expert meetings (Aug 2012 & Jan 2013)

• Full rationales to be published in June 2013

• Followed by a sister project: “Health risks of air pollution in Europe – HRAPIE” - health risk assessment, emerging issues. (June 2012-Aug 2013)
REVIHAAP contributors:

**Scientific Advisory Committee**
- H. Ross Anderson, United Kingdom
- Bert Brunekreef, The Netherlands
- Aaron Cohen, United States
- Klea Katsouyanni, Greece
- Daniel Krewski, Canada
- Wolfgang G. Kreyling, Germany
- Nino Künzli, Switzerland
- Xavier Querol, Spain

- Bart Ostro, United States
- Annette Peters, Germany
- David Phillips, United Kingdom
- C. Arden Pope III, United States
- Regula Rapp, Switzerland
- Gerd Sällsten, Sweden
- Evi Samoli, Greece
- Peter Straehl, Switzerland
- Annemoon van Erp, United States
- Heather Walton, United Kingdom
- Martin Williams, United Kingdom

- Fintan Hurley, United Kingdom
- Barry Jessiman, Canada
- Haidong Kan, China
- Thomas Kuhlbusch, Germany
- Morton Lippmann, United States
- Robert Maynard, United Kingdom
- Sylvia Medina, France
- Lidia Morawska, Australia
- Antonio Mutti, Italy
- Tim Nawrot, Belgium
- Juha Pekkanen, Finland
- Mary Ross, United States
- Jürgen Schneider, Austria
- Joel Schwartz, United States
- Frances Silverman, Canada
- Jordi Sunyer, Spain

**Authors of background text**
- Richard Atkinson, United Kingdom
- Lars Barregård, Sweden
- Tom Bellander, Sweden
- Rick Burnett, Canada
- Flemming Cassee, The Netherlands
- E. de Oliveira Fernandes, Portugal
- Francesco Forastiere, Italy
- Bertil Forsberg, Sweden
- Susann Henschel, Ireland
- Gerard Hoek, The Netherlands
- Stephen T Holgate, United Kingdom
- Nicole Janssen, The Netherlands
- Matti Jantunen, Finland
- Frank Kelly, United Kingdom
- Timo Lanki, Finland
- Inga Mills, United Kingdom
- Ian Mudway, United Kingdom
- Mark Nieuwenhuijsen, Spain

**External reviewers**
- Joseph Antó, Spain
- Alena Bartonova, Norway
- Vanessa Beaulac, Canada
- Michael Brauer, Canada
- Hyunok Choi, United States
- Bruce Fowler, United States
- Sandro Fuzzi, Italy
- Krystal Godri, Canada
- Patrick Goodman, Ireland
- Dan Greenbaum, United States
- Jonathan Grigg, United Kingdom
- Otto Hänninen, Finland
- Roy Harrison, United Kingdom
- Peter Hoet, Belgium
- Barbara Hoffmann, Germany
- Phil Hopke, United States

**Observers**
- Markus Amann, IIASA
- Arlean Rhode, CONCAWE
- Wolfgang Schoepf, IIASA
- André Zuber, European Commission

**WHO Secretariat (ECEH Bonn)**
- Marie-Eve Héroux
- Michal Krzyzanowski (up to 08.2012)
- Svetlana Cincurak
- Kelvin Fong
- Elizabet Paunovic
- Helena Shkarubo
REVIHAAP: selected conclusions on PM (A1)

The scientific conclusions of the 2005 WHO Guidelines about the evidence for a causal link between PM$_{2.5}$ and adverse health outcomes in humans have been confirmed and strengthened and, thus, clearly remain valid.

• New studies on short- and long-term effects;
• Long-term exposures to PM$_{2.5}$ are a cause of cardiovascular mortality and morbidity;
• More insight on physiological effects and plausible biological mechanisms linking short- and long-term PM$_{2.5}$ exposure with mortality and morbidity;
• Studies linking long-term exposure to PM$_{2.5}$ to several new health outcomes (e.g. atherosclerosis, adverse birth outcomes, childhood respiratory disease).
Meta-analysis of the association between long-term exposure to PM$_{2.5}$ and cardiovascular mortality

<table>
<thead>
<tr>
<th>Study</th>
<th>Pub. year</th>
<th>RR (95%CI) per 10 µg/m$^3$</th>
<th>% weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS (17)</td>
<td>2002</td>
<td>1.09 (1.03, 1.16)</td>
<td>11.22</td>
</tr>
<tr>
<td>WHI (28)</td>
<td>2007</td>
<td>1.76 (1.62, 1.91)</td>
<td>10.86</td>
</tr>
<tr>
<td>NLCSAIR (29)</td>
<td>2008</td>
<td>1.04 (0.90, 1.21)</td>
<td>9.36</td>
</tr>
<tr>
<td>Health Professionals (23)</td>
<td>2011</td>
<td>1.03 (0.83, 1.26)</td>
<td>7.79</td>
</tr>
<tr>
<td>Vancouver cohort (25)</td>
<td>2011</td>
<td>1.07 (0.86, 1.32)</td>
<td>7.59</td>
</tr>
<tr>
<td>US truckers (30)</td>
<td>2011</td>
<td>1.05 (0.93, 1.19)</td>
<td>9.92</td>
</tr>
<tr>
<td>Canadian cohort (33)</td>
<td>2012</td>
<td>1.15 (1.07, 1.24)</td>
<td>10.99</td>
</tr>
<tr>
<td>Rome cohort (39)</td>
<td>2013</td>
<td>1.06 (1.04, 1.08)</td>
<td>11.62</td>
</tr>
<tr>
<td>Six city (37)</td>
<td>2012</td>
<td>1.24 (1.12, 1.37)</td>
<td>10.43</td>
</tr>
<tr>
<td>California teachers (31)</td>
<td>2011</td>
<td>1.07 (0.96, 1.20)</td>
<td>10.21</td>
</tr>
<tr>
<td>Overall (I$^2$ = 94.1%, p = 0.000)</td>
<td></td>
<td>1.15 (1.04, 1.27)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

NOTE: Weights are from random effects analysis

LAQN Seminar, London, 21 June 2013

Hoek et al, EnvHealth 2013
Mortality and long-term exposure to PM2.5

Results of a cohort study in Rome (1.3 million adults followed from 2001 to 2010)

PM2.5: 3-dimensional Eulerian model (1x1 km)

c = % increase in risk per 10 µg/m³

Non-accidental Cause

Cardiovascular Disease

Ischemic Heart Disease

LAQN Seminar, London, 21 June 2013
Carotid artery wall thickness (=risk of atherosclerosis) and long-term PM$_{2.5}$ exposure

Heinz Nixdorf RECALL study, Ruhr region, Germany

Bauer et al, JACC 2010
Mortality and long-term PM2.5 exposure
Results of a Canadian cohort study (2.1 million adults, 1991-2001)

All non-accidental

Cardiovascular

Ischemic heart disease

Cerebrovascular

PM2.5 estimated from satellite observations + monitoring

Crouse et al, EHP 2012
REVIHAAP: selected conclusions on PM, cont.

• Both short term (such as 24-hour average) and long term (annual means) exposure to PM$_{2.5}$ affect health. (A3)

• Maintaining independent short-term and long-term limit values for ambient PM$_{10}$ in addition to PM$_{2.5}$ to protect against the health effects of both fine and coarse particles is well supported. (A4)

• In the absence of a threshold and in light of linear or supra-linear risk functions, public health benefits will result from any reduction of PM$_{2.5}$ concentrations whether or not the current levels are above or below the (EU) limit values. (A5)
REVIHAAP: selected conclusions on PM composition (A2)

- Black carbon, secondary organic aerosols, and secondary inorganic aerosols may provide valuable metrics for the effects of mixtures of pollutants from a variety of sources. (A2)

- Short-term exposures to coarse particles (including crustal material) are associated with adverse respiratory and cardiovascular health effects, including premature mortality. (A2)

- …
REVIHAAP: selected conclusions on ultrafine PM (A2)

- There is increasing, though as yet limited, epidemiological evidence on the association between short-term exposures to ultrafine (<0.1 μm) particles and cardiorespiratory health, as well as the health of the central nervous system.

- Clinical and toxicological studies have shown that ultrafine particles (in part) act through mechanisms not shared with larger particles that dominate mass-based metrics, such as PM$_{2.5}$ or PM$_{10}$. 
REVIHAAP: selected conclusions on ozone (B1)

- New evidence for an effect of long-term exposure to ozone on:
  - respiratory (and cardiorespiratory) mortality (ACS study);
  - mortality among persons with potentially predisposing conditions (COPD, diabetes, congestive heart failure, and myocardial infarction);
  - asthma incidence, asthma severity, hospital care for asthma and lung function growth.
Long term O3 exposure and risk of death due to respiratory causes
ACS cohort of 448 thousand adults followed for 18 years

RR per 10 ppb = 1.040 (95% CI 1.010 - 1.067)
(2-pollutant model with O3 and PM2.5)

Jerrett et al, NEJM 2009
Risk of asthma hospital admissions in children and mean O₃ in 1995-1999

O₃ exposure: average of daily max 8-h means in O₃ season (Apr-Oct)

Lin et al, EHP 2008
REVIHAAP: selected conclusions on ozone, cont.

- Adverse effects of exposure to daily ozone concentrations (maximum daily 1-hr or 8-hr mean) on:
  - all-cause, cardiovascular and respiratory mortality;
  - respiratory and cardiovascular hospital admissions.

- The evidence for a threshold for short term exposure is not consistent, but where a threshold is observed, it is likely to lie below 45 ppb (90 µg/m$^3$) (max 1-hr). (B2)
## Associations between short-term exposure to ozone and mortality and hospital admissions in European cities in the APHENA study

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Per cent increase in deaths/admissions (95% CI) per 10 µg/m³ increment in daily maximum 1-hour ozone concentrations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Single pollutant</strong></td>
<td><strong>Adjusted for PM$_{10}$</strong></td>
<td></td>
</tr>
<tr>
<td>All-cause mortality a</td>
<td>0.18 (0.07–0.30)</td>
<td>0.21 (0.10–0.31)</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular mortality: 75 years and older a</td>
<td>0.22 (0.00–0.45)</td>
<td>0.21 (-0.01–0.43)</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular mortality: younger than 75 years a</td>
<td>0.35 (0.12–0.58)</td>
<td>0.36 (0.10–0.62)</td>
<td></td>
</tr>
<tr>
<td>Respiratory mortality b</td>
<td>0.19 (-0.06–0.45)</td>
<td>0.21 (-0.08–0.50)</td>
<td></td>
</tr>
<tr>
<td>Cardiac admissions: older than 65 years a</td>
<td>-0.10 (-0.46–0.27)</td>
<td>0.64 (0.36–0.91)</td>
<td></td>
</tr>
<tr>
<td>Respiratory admissions: older than 65 years b</td>
<td>0.19 (-0.28–0.67)</td>
<td>0.32 (0.05–0.60)</td>
<td></td>
</tr>
</tbody>
</table>

a lag 0-1 results; b lag 1 results

*Katsouyanni et al 2009*
REVIHAAP:
selected conclusions on NO$_2$ (C2-3,D1)

- New studies document associations between day-to-day variations in NO$_2$ and variations in mortality, hospital admissions, and respiratory symptoms;
- New studies showing associations between long-term exposure to NO$_2$ and mortality and morbidity;
- Both short- and long-term studies have found these adverse associations at concentrations that were at or below the current EU LV (= WHO AQG);
- The associations between NO$_2$ and short-term health effects in many studies remain after adjustment for other pollutants (including PM$_{10}$, PM$_{2.5}$, black smoke).
- ... it is reasonable to infer that NO$_2$ has some direct effects.
- No evidence to suggest changing the averaging time for the short-term EU limit value (1-hour) (D1)
Mortality and long-term exposure to NO₂

Results of a cohort study in Rome
(1.3 million adults followed from 2001 to 2010)

NO₂ estimates: Ogawa samplers in 78 sites, 1-week in Feb, May, Oct 2007 + LUR model
Quintiles of NO₂: 37, 43, 46, 50 µg/m³

c= % increase in risk per 10 µg/m³

Non-accidental Cause

Cardiovascular Disease

Ischemic Heart Disease

AQG & EU LV

LAQN Seminar, London, 21 June 2013
## ESTIMATES OF RISK OF MORTALITY DUE TO LONG TERM NO$_2$ EXPOSURE: SINGLE- AND MULTI- POLLUTANT STUDIES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total or natural mortality estimate</th>
<th>95%CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gehring, 2006</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$ single (per 16 µg/m3) with traffic indicator</td>
<td>Rate ratio</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>no changes (data not shown)</td>
<td></td>
</tr>
<tr>
<td><strong>Jerrett, 2009</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$ single (per 4 pbb) with traffic indicator</td>
<td>Rate ratio</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>1.13</td>
<td>0.97 1.32</td>
</tr>
<tr>
<td><strong>Hart, 2011</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$<em>2$ single (per 8 pbb) with PM$</em>{10}$ and SO$_2$</td>
<td>% increase</td>
<td>8.20</td>
</tr>
<tr>
<td></td>
<td>7.40</td>
<td>2.40 12.50</td>
</tr>
<tr>
<td><strong>Cao, 2011</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOx single (per 10 µg/m3) with TSP</td>
<td>% increase</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>1.40</td>
<td>0.30 2.50</td>
</tr>
<tr>
<td><strong>Cesaroni 2013</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$<em>2$ single (per 10 µg/m3) with PM$</em>{2.5}$ with traffic indicator</td>
<td>Rate ratio</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>1.02</td>
<td>1.01 1.03</td>
</tr>
<tr>
<td></td>
<td>no changes (data not shown)</td>
<td></td>
</tr>
</tbody>
</table>

Source: HRAPIE (F. Forastiere)
**REVHAAP:** selected conclusions on health risks of proximity to roads (C1):

- Elevated health risks associated with living in close proximity to roads is unlikely to be explained by PM$_{2.5}$ mass;

- Current evidence does not allow discernment of the pollutants or pollutant combinations that are related to different health outcomes although association with tail pipe primary PM is increasingly identified;

- Toxicological research indicates that non-exhaust pollutants could be responsible for some of the observed health effects.
REVIHAAP: contribution of ambient air pollution to total exposure to regulated air pollutants (C10)

In the absence of tobacco smoke:

- Indoor, occupational and commuting exposures vary more than exposure to ambient air pollution;
- Commuting can increase exposures to PM, NO₂, CO and benzene, and is a major contributor to the exposure to UFP, BC and metals (Fe, Ni and Cu in the underground);
- Ambient air dominates population exposures to NO₂ (no gas appliances), PM$_{2.5}$, BC, O$_3$, CO and SO$_2$ (also BaP, As, Cd, Ni and Pb);
- …
REVIHAAP: contribution of ambient air pollution to total exposure to regulated air pollutants (C10) (cont.)

In the absence of tobacco smoke:

- Ambient air, indoor sources and commuting are all important for population exposures to NO$_2$ (where gas appliances are frequent), benzene and naphthalene;

- The high end of the individual exposures to PM$_{10-2.5}$ and naphthalene originate from indoor sources and commuting;

- Solid fuel fired indoor fireplaces and stoves, where used in suboptimal conditions, dominate the high end of the exposures to PM$_{2.5}$, BC, UFP, CO, benzene and BaP of the affected individuals.
REVIHAAP: Critical data gaps (A7/C9) – selected conclusions on health effects studies

- More epidemiological studies to update E-R functions based on meta-analyses for integrated risk assessment;
- The coordinated application of atmospheric science, epidemiological, controlled human exposure and toxicological studies to advance understanding of the:
  - sources responsible for the most harmful emissions,
  - physical–chemical composition of the pollution,
  - biological mechanisms that lead to adverse effects on health;
...

LAQN Seminar, London, 21 June 2013
REVIHAAP: Critical data gaps (A7/C9) – selected conclusions on health effects studies (Cont.)

- Air pollution should be considered to be one complex mix, and conditions under which this mix has the largest effect on human health need to be identified;

- Advances in atmospheric modelling, in conjunction with validation studies that use targeted monitoring campaigns, will provide a more efficient way forward in research on health effects, rather than relying on increasing the number of components measured by routine monitoring networks.
REVIHAAP Conclusions

Considerable amount of new scientific information on health effects of PM, O₃ and NO₂ observed at levels commonly present in Europe, has been published in the recent years. It:

• supports the scientific conclusions of the WHO Air Quality Guidelines updated in 2005;

• indicates that the effects can occur at air pollution concentrations lower than those serving to establish the 2005 Guidelines;

• provides scientific arguments for the decisive actions to improve air quality and reduce the burden of disease associated with air pollution in Europe.

Thank you