ASSESSING HEALTH EFFECTS OF AIR POLLUTION: IMPLICATIONS FOR AIR QUALITY MONITORING

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This presentation will be based on:

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

2. Conclusions of the WHO-EC project “Health risks of air pollution in Europe – HRAPIE: New emerging risks to health from air pollution – results from the survey of experts”
   http://www.euro.who.int/__data/assets/pdf_file/0017/234026/e96933.pdf

Emphasis: implications for AQ monitoring for
• Better understanding of health effects;
• Burden of disease assessment.
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

• Two expert meetings (Aug 2012 & Jan 2013)

• Followed by a sister project: “Health risks of air pollution in Europe – HRAPIE” - health risk assessment, emerging issues. (June 2012- Aug 2013)
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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).
The Lancet, 24 Oct 2013

IARC: Air pollution causes cancer

The carcinogenicity of outdoor air pollution

In October, 2013, 24 experts from 11 countries met at the International Agency for Research on Cancer (IARC), Lyon, France, to assess the carcinogenicity of outdoor air pollution. This assessment was the last in a series that began with specific combustion products and sources of air pollution and concluded with the complex mixture that contains all of them. The results of this most recent assessment will be published as volume 109 of the IARC Monographs.\(^1\)

Outdoor air pollution is a mixture of...
Meta-analysis of the association between long-term exposure to PM$_{2.5}$ and all-cause mortality

![Study Results]

<table>
<thead>
<tr>
<th>Study</th>
<th>RR (95%CI) per 10 µg/m$^3$</th>
<th>% weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS [18]</td>
<td>1.06 (1.02, 1.11)</td>
<td>12.11</td>
</tr>
<tr>
<td>NLCSAIR [23]</td>
<td>1.06 (0.97, 1.16)</td>
<td>4.31</td>
</tr>
<tr>
<td>Nurses Health [25]</td>
<td>1.26 (1.03, 1.55)</td>
<td>0.94</td>
</tr>
<tr>
<td>Health Professionals [29]</td>
<td>0.86 (0.72, 1.02)</td>
<td>1.30</td>
</tr>
<tr>
<td>US truckers [32]</td>
<td>1.10 (1.02, 1.18)</td>
<td>6.22</td>
</tr>
<tr>
<td>ACS Los Angeles [19]</td>
<td>1.17 (1.05, 1.30)</td>
<td>3.18</td>
</tr>
<tr>
<td>Canadian cohort [34]</td>
<td>1.10 (1.05, 1.15)</td>
<td>11.20</td>
</tr>
<tr>
<td>California teachers [36]</td>
<td>1.01 (0.94, 1.08)</td>
<td>6.53</td>
</tr>
<tr>
<td>Medicare cohort [26]</td>
<td>1.04 (1.03, 1.06)</td>
<td>23.27</td>
</tr>
<tr>
<td>Rome cohort [38]</td>
<td>1.04 (1.03, 1.05)</td>
<td>23.95</td>
</tr>
<tr>
<td>Six city [16]</td>
<td>1.14 (1.07, 1.22)</td>
<td>6.99</td>
</tr>
<tr>
<td>Overall (I$^2$ = 65.0%, p = 0.001)</td>
<td>1.062 (1.04-1.08)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

NOTE: Weights are from random effects analysis

AAMG-RSC: AQ Monitoring, London 10/12/2013
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

AAMG-RSC: AQ Monitoring, London 10/12/2013
Mean satellite-derived estimates of PM$_{2.5}$ across Canada, 2001–2006
Mortality and long-term PM2.5 exposure
Results of a Canadian cohort study (2.1 million adults, 1991-2001)

PM2.5 estimated from satellite observations + monitoring

All non-accidental

Cardiovascular

Ischemic heart disease

Cerebrovascular

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)

• ...
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

Jerrett et al., NEJM 2009

RR per 10 ppb = 1.040 (95% CI 1.010 - 1.067)
(2-pollutant model with O3 and PM2.5)
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)
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 NO$_2$

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

NO$_2$ estimates: Ogawa samplers in 78 sites, 1-week in Feb, May, Oct 2007 + LUR model
Quintiles of NO$_2$: 37, 43, 46, 50 µg/m$^3$

c= % increase in risk per 10 µg/m$^3$
## ESTIMATES OF RISK OF MORTALITY DUE TO LONG TERM NO₂ 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></td>
<td></td>
<td>Gehring, 2006</td>
</tr>
<tr>
<td>NO₂ single (per 16 µg/m³)</td>
<td>Rate ratio</td>
<td>1.19</td>
</tr>
<tr>
<td>with traffic indicator</td>
<td></td>
<td>no changes (data not shown)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jerrett, 2009</td>
</tr>
<tr>
<td>NO₂ single (per 4 pbb)</td>
<td>Rate ratio</td>
<td>1.17</td>
</tr>
<tr>
<td>with traffic indicator</td>
<td></td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hart, 2011</td>
</tr>
<tr>
<td>NO₂ single (per 8 pbb)</td>
<td>% increase</td>
<td>8.20</td>
</tr>
<tr>
<td>with PM₁₀ and SO₂</td>
<td></td>
<td>7.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cao, 2011</td>
</tr>
<tr>
<td>NOₓ single (per 10 µg/m³)</td>
<td>% increase</td>
<td>1.50</td>
</tr>
<tr>
<td>with TSP</td>
<td></td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cesaroni 2013</td>
</tr>
<tr>
<td>NO₂ single (per 10 µg/m³)</td>
<td>Rate ratio</td>
<td>1.03</td>
</tr>
<tr>
<td>with PM₂.₅</td>
<td></td>
<td>1.02</td>
</tr>
<tr>
<td>with traffic indicator</td>
<td></td>
<td>no changes (data not shown)</td>
</tr>
</tbody>
</table>

Source: HRAPIE (F. Forastiere)
INDIVIDUAL AND MULTI-POLLUTANT CUMULATIVE HAZARD RATIOS: IHD MORTALITY

18 years follow up of 73,711 subjects from ACS cohort in California
PM2.5 and NO2: LUR models
O3: inverse distance weighting interpolation

Selected conclusions:
• Several combustion-related components related to mortality
• Study effects of NO2 and O3 jointly
• Increase precision of O3 exposure assessment

Jerrett et al, AJRCCM 2013
REVIHAAP: 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: Critical data gaps (A7/C9) – selected conclusions on health effects studies

- 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;

- 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.
HRAPIE survey on new emerging issues on health risks from air pollution

QUESTION:
Is there evidence of new emerging issues on risks to health from air pollution, either related to specific source categories (e.g. transport, biomass combustion, metals industry, refineries, power production), specific gaseous pollutants or specific components of particulate matter (e.g. size-range like nano-particles and ultra-fines, rare-earth metals, black carbon (EC/OC))? 

METHOD:
• Web-based survey implemented in May 2013;
• 11 questions (multiple choice format) for all and each emission source category + respondent characterization data (optional);
• Open invitation to AQ & health experts (direct and through WHO EH focal points, UN LRTAP, EEA, ERS, ISEE, EUROCITIES network, EU DG R&I, HEAL)


AAMG-RSC: AQ Monitoring, London 10/12/2013
HRAPIE survey: respondent country of residence

TOTAL NUMBER OF RESPONDENTS = 100;
Country of residence reported by 47

- United States of America: 81%
- WHO European Region (non-EU28): 11%
- EU28: 81%
- Netherlands: 15%
- Italy: 11%
- Belgium: 9%
- Spain: 9%
- Germany: 6%
- Ireland: 6%
- France: 4%
- Sweden: 4%
- United Kingdom: 4%
- Austria: 2%
- Croatia: 2%
- Czech Republic: 2%
- Greece: 2%
- Poland: 2%
- Slovenia: 2%
HRAPIE survey: respondent work sector

TOTAL NUMBER OF RESPONDENTS = 100;
Country of residence reported by 52
HRAPIE survey: knowledge gaps requiring further research (all source categories)

- Other (specified) 3%
- Biological mechanism of action 13%
- Ability to assess/measure the health effect 16%
- Exposure 68%
- Concentration 10%
- Chemical and physical characteristics 9%
- Duration 9%
- Individual microenvironments 10%
- Changes over time 9%
- Assessed pollutant might act as a proxy 7%
- Personal exposure 13%

AAMG-RSC: AQ Monitoring, London 10/12/2013

WHO 2013
HRAPIE survey: ambient air pollutants that pose a health risk (all source categories)

- Organic carbon (OC)/secondary organic aerosols (SOAs) 4.2%
- Non-methane volatile organic compounds (NMVOCs) 2.4%
- Volatile organic compounds (VOCs) 4.1%
- Polycyclic aromatic hydrocarbons (PAHs) 5.6%
- Hydrocarbons (HCs) 2.4%
- Carbon monoxide (CO) 3.2%
- Ammonia (NH₃) 1.8%
- Other (specified) 0.7%
- Metals (general) 1.0%
- Arsenic 1.1%
- Cadmium 1.3%
- Mercury 0.8%
- Lead 1.7%
- Nickel 2.3%
- Copper 1.4%
- Zinc 1.0%
- Manganese 1.6%
- Iron 2.0%
- Antimon 1.1%
- Vanadium 2.0%
- Aluminium 0.1%
- Transition metals (general) 0.3%

UFP 14.2%
HRAPIE survey: emission source categories requiring further research

- Road transport: 40.7%
- Industrial processes (metal industries): 6.2%
- Energy production and distribution: 6.2%
- Shipping: 8.8%
- Agriculture: 5.3%
- Space heating and air conditioning: 15.0%
- Other (specified): 0.9%
- Solvent and product use: 0.0%
- Energy use in industry: 0.9%
- Waste: 1.8%
- Construction and demolition activities: 2.7%
- Aviation and airports: 2.7%
- Non-road transport (other): 2.7%
- Natural sources: 2.7%
- Refineries: 2.7%
HRAPIE survey: exposure characteristics for future consideration

- Road transport
  - Exposure situation / microenv.
  - New property of pollutant(s)

- Space heating, air conditioning
  - Exposure situation / microenv.
  - New property of pollutant(s)

WHO 2013
PM2.5 estimated from PM10 and directly measured used for GBD2010 project

Data for 2005 (or 2004-2006)

- Measured - 475 loc., 90%: high income countr.
- Estimated from PM10

Brauer et al, Env Sc Technol. 2012
Estimated 2005 annual average PM2.5 concentrations – GBD2010 project

PM 2.5 estimates based on satellite data, TM5 model and calibrated with surface measurements.

Brauer et al, Env Sc Technol. 2012
GBD2010 study
Lim et al, Lancet 2012
Exposure to PM10 in 1100 urban areas, 2003-2010

Annual mean PM10 (ug/m3)
- <20
- 20–29
- 30–49
- 50–99
- 100–149
- ≥150
- Not applicable

* The mean annual concentration of fine suspended particles of less than 10 microns in diameters is a common measure of air pollution. The mean is a population-weighted average for urban population in cities above 100,000 inhabitants of a country.
Global availability of PM data, 2003-2010

WHO 2011

- 569 cities
- 1099 cities
Conclusions (1 of 2)

Considerable amount of new scientific information on health effects of PM, O$_3$ and NO$_2$ 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.
Conclusions (2 of 2)

• Further understanding of health effects of air pollution needs further advance in exposure assessment (modelling + monitoring):
  • simultaneous assessment of various components of the pollution mixture;
  • further reduction of exposure assessment error in epi studies;
  • expansion of the parameters assessed (including UFP, metals, BC…)

• Assessment of burden of disease requires:
  • expansion of PM2.5 monitoring in lower-income countries (simple, reliable, low cost methods);
  • progress in chemical transport models and remote sensing;
  • integration of data from different sources and based on various methodologies.

Thank you