Acute (or short-term) human health effects of particulate air pollution: epidemiologic evidence for the relevance of ultrafine particles

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The health effects of air pollution are often classified for convenience into short- and long-term effects, although there is most probably a continuum of effects on the time scale, not yet completely understood. The epidemiological study designs specifically address the hypotheses according to the time scale of exposure investigated.

One study design that is relatively easy to implement and through which we have gained extensive knowledge on the health effects of specific pollutants is the time-series design. I will focus here in the presentation of evidence from time-series studies on the health effects of Ultrafine Particles (UFP). This design uses aggregated data, usually daily, often based on routinely collected information. Thus usually there is data availability for long time series and the design yields statistically powerful tests. As the same population is used as exposed (on high pollution days) and as "control" (on low pollution days) no confounding by individual characteristics is probable; potential confounding has to be taken into account by variables which vary on daily basis.

A large evidence base for the effects of regulated particulate indices has accumulated. European studies have evaluated the effects of black smoke and those of PM_{10}, whilst there is less evidence on $PM_{2.5}$ as they have been regulated only since 2008. In the U.S., both PM_{10} and $PM_{2.5}$ have been extensively studied. Thus from multi-center studies and meta-analyses, we know that in Europe an increase of 20μg/m^3 in the daily PM_{10} concentration is associated with an increase of 1 to 1.2% in the daily number of deaths and the corresponding figure in the U.S. is about 0.7%. The effects are slightly higher for cardiovascular, respiratory and cardio-respiratory mortality. From U.S. studies, it is estimated that an increase of 10μg/m^3 is associated with about 1% increase in the daily all cause mortality, with, again, slightly higher estimates for specific causes. When longer time periods of exposure are assessed (up to 1.5 months and even up to one year) effects are larger. The prolonged effects are much more pronounced for respiratory deaths.

As a consensus was formed about the reality of health effects of particulate pollution, the question of which particle characteristics make the mixture more toxic for human health effects became very important. Evidence from toxicology suggested that smaller particles can affect human health in various biological ways. Epidemiological studies in human populations were needed to investigate the effects of UFP on relevant health outcomes. UFP are a small portion of the mass measured, but represent a large proportion of the number of particles. Therefore particle number concentration (PNC) is thought to be a good indicator of UFP. Particle surface area has also been proposed, with limited use, as no technology for routine measurements is yet in place.

The lack of sufficient (i.e. daily, or at least near-daily) measurements in most situations led to studies driven by data availability, not necessarily conducted in the most interesting locations. Studies used various methods of measurement (and different cutoff diameters when measuring the number of particles), sometimes not comparable. Also the outcomes varied based on availability or on specific prior hypotheses.

An expert elicitation (Hoek et al 2010) has provided estimates on the short-term effects of UFP on the total daily number of deaths with a median of 0.3% per 1000particles/cm^3. This estimate is identical to that provided by a study conducted in Erfurt (Stolzel et al 2007). A later study in London (Atkinson et al 2010) provided a smaller estimate (1.4%) and one in Prague a larger one (0.9% Branis et al 2010). Similar (but variable) effect sizes have been estimated in 4 studies investigating cardiovascular deaths (Stolzel et al 2007; Atkinson et al 2010; Branis et al 2010; Breitner et al 2011) whilst one study in Helsinki gave null estimates (Halonen et al 2009). Positive and significant effects have been found with ischemic heart disease mortality (Forastiere et al 2006 and Breitner et al 2011) and a highly positive but not statistically significant effect with mortality from stroke (Kettunen et al 2012). A few studies investigated respiratory mortality and found positive effects although not reaching the nominal level of statistical significance (Atkinson et al 2010; Branis et al 2010; Halonen et al 2009).

Several studies examined various cardiovascular morbidity outcomes. The HEAPSS study, which included myocardial infarction survivors from 5 European cities, found significant effects for cardiac re-admissions and fatal myocardial infarction effects of UFP exposure (Von Klot et al 2006; Lanki et al 2006). Other studies generally found non-significant results, however indicating elevations in cardiovascular morbidity outcomes associated with UFP exposure (Andersen et al 2008; Halonen et al 2009; Atkinson et al 2010; Belleudi et al 2010; Branis et al 2010). Effects of similar magnitude, or even larger, have been reported for respiratory morbidity outcomes as well (Andersen et al 2008; Halonen et al 2009; Atkinson et al 2010; Belleudi et al 2010; Branis et al 2010).

In conclusion, there is evidence on the short-term effects of UFP on several mortality and morbidity outcomes, but still a consistent picture cannot be detected due to the lack of standardization in the studies, the lack of multi-city studies and the lack of long series of measurements.

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Outline

- Context – Definitions – Study design
- What we know on the short-term effects of particulate matter on health from time series studies
- What we know on the short-term effects of ultrafine particles on health from time series studies
- Conclusions – Discussion points – Future needs

THE EFFECTS OF AIR POLLUTION ON HEALTH ARE OFTEN CONVENIENTLY CLASSIFIED:

In short-term and long-term effects

although there is probably a continuum of effects in the time scale, which are not yet fully understood.

What is meant by "short-term" in this presentation?

- The effects manifested within the same day or in the next few days (say, up to a week) after a specific exposure to an air pollutant or a mixture of air pollutants.

Usual study designs for the investigation of short-term effects (1)

- Time series studies (aggregated data; usually daily; based on routinely collected information; long time series; no confounding by individual characteristics; potential confounding by variables which vary on daily basis; pollution measurements often by fixed monitors). Concern aggregated data, large populations and long time periods.

Usual study designs for the investigation of short-term effects (2)

- Panel studies (cohort followed intensively for relatively short time; individual data; usually daily; no confounding by individual characteristics; potential confounding by variables which vary on daily basis; analysis may be done with aggregated or with individual data; pollution measurements may be individualized). Concern individual data, small number of participants, shorter time periods.

- Experimental studies with planned exposures to specific outdoor locations or trajectories; or controlled artificial exposures. Concern smaller number of participants, individual data.

Focus on time series studies

- During the late 80's and early 90's several time-series studies produced evidence of short-term effects at relatively low levels of pollution

- Their results were put in a broader context and were consolidated with the initiation of large multi-city studies in Europe and the U.S.

Exposure metrics used

- Mainly the metrics which were regulated at each time period, thus ensuring adequate series of measurements of standardized quality

- For Europe Black Smoke, later Particles with an aerodynamic diameter <10μm (PM_{10}) and more recently $PM_{2.5}$; for the U.S, PM_{10} and $PM_{2.5}$

Percent Increase in mortality risk associated with an increase of 20 μg/m^3 in PM_{10} (Pope *Inhalation Toxicology* 2007)

Short-term Effects

		Percent Increase in mortality risk (95% Confidence Interval- CI)	
Study area and types	Primary sources	All cause	Cardiovascular/ Cardiopulmonary
Meta-estimate from single-city studies Adjusted for publication bias	Anderson et al. (2005)	1.2 (1.0, 1.4) 1.0 (0.8, 1.2)	
Meta-estimates from COMEAP	COMEAP (2006)		1.8 (1.4, 2.4)[a]
U.S. 10 cities	Schwartz (2000, 2003)	1.3 (1.0, 1.6)	
U.S. 14-city case-crossover	Schwartz (2004)	0.7 (0.4, 1.0)	
NMMAPS 20-100 U.S. cities	Dominici et al. (2003)	0.4 (0.2, 0.8)	0.6 (0.3,1.0)[b]
APHEA-2 15-29 European cities	Katsouyanni et al. (2001) Analitis et al. (2006)	1.2 (0.8, 1.4)	1.5 (0.9,2.1)[a]

[a]Cardiovascular only [b]Cardiovascular and respiratory deaths combined

Percent Increase in mortality risk associated with an increase of 10 μg/m^3 in $PM_{2.5}$ (Pope *Inhalation Toxicology* 2007)

Short-term Effects

		Percent Increase in mortality risk (95% Confidence Interval)	
Study area and types	Primary sources	All cause	Cardiovascular/ Cardiopulmonary
Meta-estimates from COMEAP	COMEAP (2006)		1.4 (0.7,2.2) [a]
U.S. 6 cities	Klemm and Mason (2003)	1.2 (0.8, 1.6)	1.3 (0.3,2.4) [c]
California 9 cities	Ostro et al. (2006)	0.6 (0.2, 1.0)	0.6 (0.0, 1.1)[a]

[a]Cardiovascular only [c]Ischemic heart disease deaths

Percent Increase in mortality risk associated with particulate matter-PM_{10} (Pope *Inhalation Toxicology* 2007)

Comparison of estimated excess risk of all cause mortality estimates for different time scales of exposure

Study area and types	Primary sources	Time scale of exposure				
		1 day	2 days	5 days	40 days	About 1 year
10 U.S. cities, time-series, distributed lag	Schwartz (2000)	1.3	2.1	2.6		
10 European cities, APHEA time-series distributed lag	Zanobetti et al. (2002)		1.4		3.3	
Dublin daily time-series, distributed lag, intervention	Goodman et al. (2004) Clancy et al. (2002)	0.8			2.2	3.2
Utah Valley, time series and ntervention	Pope et al. (1992)			3.1		4.3
Harvard six cities, time-series and cohort extended analysis	Schwartz et al. (1996) Klemm and Mason (2003) Laden et al. (2006)		1.2			14

Percent Increase in mortality risk associated with particulate matter – PM_{10} (Pope *Inhalation Toxicology* 2007)

Comparison of estimated excess risk of cause specific mortality estimates for different time scales of exposure

Study area and types	Primary sources	Cardiovascular/ cardiopulmonary Time scale of exposure					Respiratory Time scale of exposure				
		1 day	2days	20 days	40 days	1 year	1 day	2 days	20 days	40 days	1 year
10 European cities, APHEA, time-series distributed lag	Zanobetti et al. (2002)		1.4	2.7	4.0			1.5	3.4	8.6	
Dublin daily time-series distributed lag intervention	Goodman et al. (2004) Clancy et al. (2002)	0.8			2.2	5.7	1.8			7.2	8.7

From the previous slides it is worth noting that the respiratory effects are consistently more prolonged compared to cardio-vascular (no papers from the US point to the lack of daily data)

Short-term effects of PM pollution on hospital cardiovascular admissions. Results from the multi-centre European project APHEA based on 8 cities (Le Tertre et al, JECH 2002; 56:773-9).

	% (95% CI) increase in outcome associated with 10μg/m³ increase in pollutant	
Admission series	**PM_{10}**	**Black smoke**
All cardiac	0.5 (0.2, 0.8)	1.1 (0.4, 1.8)
Cardiac 65+ yrs	0.7 (0.4, 1.0)	1.3 (0.4, 2.2)
IHD <65 yrs	0.3 (-0.2, 0.7)	0.1 (-0.4, 0.5)
IHD 65+ yrs	0.8 (0.3, 1.2)	1.1 (0.6, 1.6)
Stroke 65+yrs	0.0 (-0.3, 0.3)	0.0 (-0.7, 0.6)

Short-term effects of PM pollution on hospital respiratory admissions. Results from the multi-centre European project APHEA based on 8 cities (Atkinson et al, AJRCCM 2002; 164:1860-6).

	% (95% CI) increase in outcome associated with 10μg/m^3 increase in pollutant	
Admission series	**PM_{10}**	**Black smoke**
Asthma 0-14 yrs	1.2 (0.2, 2.3)	1.3 (0.3, 2.4)
Asthma 15-64 yrs	1.1 (0.3, 1.8)	0.7 (-0.3, 1.8)
COPD + asthma 65+ yrs	1.0 (0.4, 1.5)	0.2 (-0.7, 1.1)
All respiratory 65+ yrs	0.9 (0.6, 1.3)	0.1 (-0.7, 0.9)

To sum-up: what do we know

- Stable results from meta-analyses and multi-center studies.
- There is an increase in the daily total mortality of about 1.2% in Europe and about 0.7% in the US associated with 20 $\mu g/m^3$ increase in the 2-day average PM_{10} concentration.
- The effect is somewhat larger for cardiovascular and respiratory deaths.
- Results on PM2.5 effects are mainly from US and show analogous effects.
- For longer the time periods of exposure, larger effects are observed. Respiratory outcomes particularly show more lagged effects.
- Effects known on morbidity outcomes (higher for respiratory).

Which particle characteristics make the mixture more toxic for human health effects?

- As a consensus was formed about the reality of health effects of particulate pollution, the above question became very important

- Evidence from toxicology suggested that smaller particles can affect human health in various biological ways

- Epidemiological studies in human populations were needed to investigate the effects of ultrafine particles (UFP) on relevant health outcomes

Time series studies on the effects of ultrafine particles (UFP)

- UFP are a small portion of the mass measured, but **represent a large proportion of the number of PM**. Therefore particle number concentrations (**PNC**) are thought to be a **good indicator** of UFP. Particle surface area has also been proposed, with limited use, as no technology for routine measurements is in place

- The lack of sufficient (i.e. daily, or at least near-daily) measurements in most situations leads to studies driven by data availability

Time series studies on the effects of ultrafine particles (continued)

- Thus, studies are done in locations where measurements have been conducted with the initiative of researchers and not necessarily in the most interesting locations
- Studies use various methods of measurement (and different cutoff diameters for particles when measuring their number), sometimes not comparable.
- Also the outcomes vary based on availability or on specific prior hypotheses

Are ultrafines the "causal" factor or an index of correlated pollutants?

- There are ways to attempt to estimate the independent effects of ultrafines (independent, mainly of $PM_{2.5}$ and PM_{10})
- However this is not always straightforward, as the various indices are correlated over time
- Most studies conducted to date have attempted this separation, or at least, a comparison between effects of the various metrics
- There has been en expert solicitation (Hoek et al 2010) which considered all cause mortality and cardiovascular and respiratory admissions with data up to 2008
- In the next few slides, I will try to summarize the main messages of key publications

UFP and mortality outcomes: total mortality

Publication	Lag chosen for UFP PNC	PNC effect % increase (95% CI)	PM_{10} effect % increase (95% CI)	$PM_{2.5}$ effect % increase (95% CI)
Atkinson et al 2010, London 2000-05	1	**1.4** per 10166/cm^3 (0.5, 2.4)	0.5 per 14µg/m^3 (-0.03, 1.01)	-0.04 per 11µg/m^3 (-0.5, 0.4)
% missing		31	20	12
Stolzel et al 2007, Erfurt 1995-01	4	**2.9** per 9748/cm^3 (0.3, 5.5)	-0.07 per 23µg/m^3 (-0.03, 1.5)	0.2 per 16µg/m^3 (-1.8, 2.2)
% missing		11	0	9
Branis et al 2010 Prague 2006	2	**0.9** per 1000/cm^3 (-0.4, 2.2)	NA	0.0 per 10 µg/m^3 (-1.2, 1.0)
% missing		22		0

UFP and total mortality outcomes: Comments

- In the Stolzel paper, PM10 and PM2.5 had larger effects (nss) at lags 0-1
- Differences in lags
- Large missing % in UFP compared to PM_{10} or $PM_{2.5}$
- Expert solicitation (Hoek et al 2010)

UFP and mortality outcomes: Cardiovascular Disease (CVD) mortality

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Atkinson et al 2010	CVD 1 (London- 6yrs)	**2.2** per 10166/cm^3 (0.6, 3.8)	0.1 per 14µg/m^3 (-0.8, 1.0)	-0.2 per 11µg/m^3 (-0.9, 0.5)
Stolzel et al 2007	Cardio-resp. 4 (Erfurt- 7yrs)	**3.1** per 9748/cm^3 (0.3, 6.0)	-0.6 per 23µg/m^3 (-3.0, 1.8)	0.1 per 16µg/m^3 (-0.2, 2.2)
Breitner et al 2011	CVD 2 (Beijing- <2yrs)	**4.0** per 6250/cm^3 (1.8, 7.0)	NA	NA
Branis et al 2010	CVD 2 (Prague- 1yr)	**1.1** per 1000/cm^3 (-0.9, 3.1)	NA	-1.2 per 10µg/m^3 (-2.9, 0.4)
Halonen et al 2009	CVD 0 (Helsinki- 7yrs)	**0.03** per 2467/cm^3 (-1.8, 1.9)	NA	0.7 per 6µg/m^3 (-0.7, 2.1)

UFP and Cardiovascular Disease (CVD) mortality outcomes: Comments

- Three papers report statistically significant effects of PNC on cardiovascular mortality, roughly from 2 to 7% increase per 10000/cm^3 in PNC
- Differences in lags/ Missing measurements
- Are studies underpowered? (Small populations, short time periods, incomplete time series).

UFP and mortality outcomes: Cardiovascular Disease (CVD) mortality (continued)

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Forastiere et al 2006	Out-of-hosp coronary death 0 (Rome- 3 yrs)	**7.6** per 27790/cm^3 (2.0, 13.6)	4.8 per 30/cm^3 (0.1, 9.8)	NA
Breitner et al 2011	IHD* mortality 2 (Beijing- <2yrs)	**7.3** per 6250/cm^3 (2.9, 11.5)	NA	NA
Kettunen et al 2012	Stroke mortality 1 (Helsinki- 7yrs) Warm season	**8.5** per 4979/cm^3 (-1.2, 19.1)	8.6 per 10µg/m^3 (-1.2, 18.9)	7.4 per 6µg/m^3 (1.3, 13.8)

*Ischemic Heart Disease

Comment: In this Table results for more specific mortality causes are presented and they are more evident and significant

UFP and mortality outcomes: respiratory mortality

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Atkinson et al 2010	Respiratory 1 (London- 6yrs)	**2.3** per 10166/cm^3 (-0.1, 4.8)	0.1 per 14µg/m^3 (-0.2, 2.4)	0.5 per 11µg/m^3 (-0.5, 1.6)
Branis et al 2010	Respiratory 2 (Prague- 1yr)	**0.4** per 1000/cm^3 (-4.7, 5.8)	NA	0.3 per 10µg/m^3 (-1.1, 7.2)
Halonen et al 2009	Respiratory 1 (Helsinki- 7yrs)	**3.3** per 2467/cm^3 (-0.8, 7.5)	NA	1.6 per 6µg/m^3 (-1.4, 4.7)

Comment: The evidence is more limited for respiratory mortality. Power is smaller since respiratory deaths are much fewer. However, respiratory outcomes should not be neglected.

UFP and morbidity outcomes: Cardiovascular Diseases

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Von Klot et al 2006	Cardiac re-adm 0 (5 EU cities-HEAPSS)	**2.6** per 10000/cm^3 (0.5, 4.8)	2.1 per 10µg/m^3 (0.4, 3.9)	NA
Lanki et al 2006	Fatal acute MI 1 (3 EU cities-HEAPSS)	**5.8** per 10000/cm^3 (1.2, 10.7)	2.6 per 10µg/m^3 (-0.6, 5.8)	NA
Andersen et al 2008	CVD hosp adm >65yrs 0-3 (Copenhagen)	**0** per 3907/cm^3 (-0.1, 0.2)	3.0 per 13µg/m^3 (1.0, 6.0)	3.0 per 5µg/m^3 (1.0, 6.0)
Halonen et al 2009	CHD hosp adm 2 (Helsinki- 7yrs)	**0.4** per 2467/cm^3 (-1.3, 2.2)	NA	-0.6 per 6µg/m^3 (-1.9, 0.6)
Halonen et al 2009	Stroke hosp adm 1 (Helsinki- 7yrs)	**1.0** per 2467/cm^3 (-1.4, 3.4)	NA	0.02 per 6µg/m^3 (-1.7, 1.8)

UFP and morbidity outcomes: Cardiovascular Diseases (CVD) (continued)

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Halonen et al 2009	Arrhythmia hosp 2 (Helsinki- 7yrs)	**0.3** per 2467/cm^3 (-2.0, 2.7)	NA	-0.1 per 6µg/m^3 (-1.8, 1.7)
Atkinson et al 2010	CVD hosp adm 0 (London- 6yrs)	**0.7** per 10166/cm^3 (-0.4, 1.7)	0.4 per 14µg/m^3 (-0.2, 0.9)	0.4 per 11µg/m^3 (-0.1, 0.9)
Belleudi et al 2010	Acute Coronary Syndrome hosp a 2 (Rome- 5yrs)	**0.2** per 9392/cm^3 (-1.0, 1.4)	1.0 per 14µg/m^3 (0.0, 2.1)	2.0 per 10µg/m^3 (0.3, 3.7)
Belleudi et al 2010	Heart failure adm 2 (Rome- 5yrs)	**1.7** per 9392/cm^3 (0.3, 3.0)	0.4 per 14µg/m^3 (-1.2, 2.0)	1.0 per 10µg/m^3 (-0.9, 2.8)
Branis et al 2010	CVD hosp adm 1 (Prague- 1yrs)	**1.1** per 1000/cm^3 (-0.4, 2.5)	NA	0.9 per 10µg/m^3 (0.0, 2.0)

UFP and Cardiovascular Disease morbidity outcomes: Comments

- Importance of multi-center studies
- Effects on sensitive sub-groups
- All single city studies – except one – report positive associations, not statistically significant. High variation in the estimates.
- Lack of standardization
- Expert solicitation (Hoek et al 2010)

UFP and morbidity outcomes: respiratory

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Andersen et al 2008	Resp hosp adm. >65yrs 0-4 (Copenhagen)	**4.0** per 3907/cm^3 (0.0, 7.0)	6.0 per 13µg/m^3 (2.0, 9.0)	0.0 per 5µg/m^3 (-0.5, 0.5)
Halonen et al 2009	Asthma+COPD* 1 (Helsinki- 7yrs)	**1.7** per 2467/cm^3 (-1.4, 3.4)	NA	2.6 per 6µg/m^3 (0.8, 4.5)
Halonen et al 2009	Pneumonia hosp a 1 (Helsinki- 7yrs)	**1.6** per 2467/cm^3 (-0.7, 4.1)	NA	2.4 per 6µg/m^3 (0.6, 4.2)
Branis et al 2010	Resp hosp adm 1 (Prague- 1yrs)	**2.3** per 1000/cm^3 (0.0, 4.9)	NA	1.1 per 10µg/m^3 (-0.8, 3.0)
Atkinson et al 2010	Resp hosp adm >65yrs 4 (London- 6yrs)	**1.3** per 10166/cm^3 (-0.1, 2.7)	0.7 per 14µg/m^3 (-0.2, 1.5)	0.9 per 11µg/m^3 (0.2, 1.6)

*Chronic Obstructive Pulmonary Disease

Publication	Specific outcome Lag (Location)	PNC effect % incr(95% CI)	PM_{10} effect % incr(95% CI)	$PM_{2.5}$ effect % incr(95% CI)
Belleudi et al 2010	LRTI* hosp adm 2 (Rome- 5yrs)	**0.2** per 9392/cm^3 (-1.5, 1.9)	2.2 per 14µg/m^3 (0.2, 4.2)	2.8 per 10µg/m^3 (0.5, 5.2)
Belleudi et al 2010	COPD* hosp adm 1 (Rome- 5yrs)	**0.2** per 9392/cm^3 (-1.3, 1.6)	-1.2 per 14µg/m^3 (-2.9, 0.5)	-2.5 per 10µg/m^3 (-4.4, -0.5)
Atkinson et al 2010	Resp hosp adm 0-14yrs 1 (London- 6yrs)	**1.3** per 10166/cm^3 (-0.6, 3.2)	0.5 per 14µg/m^3 (-0.7, 1.6)	0.9 per 11µg/m^3 (-0.1, 1.8)
Leitte et al 2010	Emergency Respiratory Visits 3 (Beijing- 3 yrs)	**8** per 3600/ cm^3 (0.0, 17)	1 per 90 µg/m^3 (-3.0, 5.0)	NA
Andersen et al 2008	Asthma hosp adm. 5-18yrs 0-5 (Copenhagen)	**7.0** per 3907/cm^3 (-0.2, 17.0)	2.0 per 13µg/m^3 (-0.7, 12.0)	15.0 per 5µg/m^3 (0.0, 32.0)

* Lower Respiratory Track Infections * Chronic Obstructive Pulmonary Disease

UFP and respiratory morbidity outcomes: Comments

- The effects on respiratory morbidity appear more pronounced compared to cardiovascular morbidity outcomes, often with larger effect estimates
- Short lags are observed (exception the Atkinson paper)
- Lack of standardization
- Expert solicitation (Hoek et al 2010)

Conclusions- Discussion points – Future needs

- There is evidence on the short-term health effects of UFP, but not yet clear and consistent
- Need for better and more measurements, designed for the needs of health studies
- Need for multi-center standardized studies
- Cardiovascular and respiratory outcomes appear to be important