Health Effects of Short-Term Exposure to PM, NO_2 & O_3

October 2022

In 2021, the World Health Organisation (WHO) published revised recommendations for ambient air quality (WHO 2021). To support this update, WHO published a review paper in 2020 evaluating all the available evidence on the effects of short-term exposure to particulate matter (PM) and nitrogen dioxide (NO_2) (Orellano et al. 2020).

Specifically, the research published updated quantified risk ratios for exposure to PM, NO_2 and O_3 on premature mortality (people dying earlier than they otherwise would have). They also assessed how this risk changed at different levels of exposure.

Highlights

- Associations between short-term exposure to PM_{10}, $PM_{2.5}$, NO_2 and O_3 and all-cause and cause-specific mortality were evaluated.
- Increased short-term concentrations of PM_{10}, $PM_{2.5}$, NO_2 and O_3 were found to increase the risk of all-cause mortality.
- Increased daily levels of PM_{10} and $PM_{2.5}$ were found to increase the risk of cardiovascular, respiratory and cerebrovascular mortality.
- The relationships were generally linear and did not detect a threshold, except for daily exposure to nitrogen dioxide, which showed some evidence of a threshold.
- In general, the level of evidence was high, meaning that we can be confident in the associations found in this study.

(Orellano *et al*. 2020)

Key Facts

This study found evidence of a positive association between short-term exposure to PM_{10}, $PM_{2.5}$, NO_2 and O_3 and all-cause mortality, and between PM_{10} and $PM_{2.5}$ and cardiovascular, respiratory and cerebrovascular mortality. These results were robust through several sensitivity analyses.

As noted in the paper, small risks applied to large populations are likely to represent a major health problem. This means that while the risk ratios are numerically small (<1%), the health burden can still be significant when multiplied across the entire population exposed.

Nitrogen dioxide

Epidemiological studies of NO_2 exposure are often unable to separate the effects of NO_2 from other pollutants, especially fine particles. This is because NO_2 concentrations closely follow vehicle emissions (WHO 2006). However, in this study the associations were observed even after the adjustment by a second pollutant, at least in some combinations of pollutants and outcomes. This supports the hypothesis of a positive association between short-term NO_2 exposure and human mortality.

Research Findings

Following screening and selection, Orellano and fellow researchers systematically reviewed 196 air pollution epidemiology studies. Mean/median daily concentrations of $PM_{2.5}$ in 60 studies ranged from 5.7 – 177 micrograms per cubic metre (µg/m³) and mean/median daily concentrations of PM_{10} in 114 studies ranged from 14 – 245 µg/m³. Mean/median daily concentrations of NO_2 in 66 studies ranged from 18 – 99 µg/m³ and mean/median hourly concentrations in 9 studies ranged from 40 – 161 µg/m³. Mean/median daily concentrations of O_3 in 48 studies ranged from 15 – 206 µg/m³.

The studies were published between 1992 and 2019, with the majority being carried out in Asia (73), Europe (69) and America (45). Three studies comprised more than one continent. Only three studies were from Oceania (Australia), with no studies in New Zealand.

Orellano and fellow researcher's developed new risk ratios as presented below, to represent the quantitative risks posed by short-term exposure to PM and NO_2.

Pollutant / Time Average	Mortality	No. Studies	Risk Ratio	95% Confidence Interval	Certainty of Evidence
PM_{10} 24-hour	All-cause	66	1.0041	1.0034 – 1.0049	**High**
	Cardiovascular	44	1.0060	1.0044 – 1.0077	**High**
	Respiratory	41	1.0091	1.0063 – 1.0119	**High**
	Cerebrovascular	20	1.0044	1.0022 – 1.0066	**High**
$PM_{2.5}$ 24-hour	All-cause	29	1.0065	1.0044 – 1.0086	**High**
	Cardiovascular	28	1.0092	1.0061 – 1.0123	**High**
	Respiratory	20	1.0073	1.0029 – 1.0116	**High**
	Cerebrovascular	7	1.0072	1.0012 – 1.0132	**High**
NO_2					
24-hour	All-cause	54	1.0072	1.0059 – 1.0085	**High**
1-hour	All-cause	10	1.0024	0.9995 – 1.0053	Moderate
O_3 24-hour or 8-hour	All-cause	48	1.0043	1.0034 – 1.0052	**High**

The risk ratio can be interpreted as follows:

Daily $PM_{2.5}$ risk ratio 1.0065 (95% *Confidence Interval*:1.0044, 1.0086, n = 29)[1]

[1] For more information on the study methods and interpreting risk ratios please see the separate fact sheet titled "Health Effects of Air Pollutant Factsheets: Supporting Information". (Wickham *et al*. 2022a)

This means for every 10 µg/m^3 increase in daily concentrations of $PM_{2.5}$, deaths in the wider population due to all causes increased by 0.65%, with 95% of the data being between 0.4 – 0.8% in 29 epidemiological studies.

The association was non-significant for 1-hour nitrogen dioxide.

Discussion

The researchers noted the following important observations:

- This systematic review and *meta*-analysis found **evidence of a positive association between short-term exposure to PM_{10}, $PM_{2.5}$, NO_2 and O_3 and all-cause mortality in people**. It also found a positive association between daily exposure to $PM_{2.5}$ and PM_{10} and cardiovascular, respiratory and cerebrovascular mortality.
- The **magnitude of the associations was, as expected, lower than the associations between mortality and exposure to these same air pollutants in the long-term** (i.e. annual exposure). In epidemiology small risks applied to large populations are likely to represent a major health problem. A larger magnitude in long-term studies might be from cumulative effects (Beverland *et al*. 2012), due to the fact that short-term exposure studies only take into account a small proportion of the health effects; in addition, adverse effects are dependent on both concentration and length of exposure (Pope 2007).
- In general, **linear concentration response functions were found for $PM_{2.5}$ and PM_{10} associated with all-cause and cause-specific mortality**. There was no evidence of any threshold. This suggests that health improvements are still to be found by reducing PM levels at all levels.
- Whilst most (13 of 16) studies of daily exposure to **NO_2 found a linear response, a few were non-linear and one study showed a potential threshold of 37.6 µg/m^3** (Moolgavkar *et al.* 2013).
- Application of WHO's risk of bias tool (WHO 2020) showed that a **considerable number of studies were at a high risk of bias, but only in the missing data domain**. Sensitivity analyses confirmed the positive associations found, when excluding studies with a high risk of bias.
- Assessment of publication bias concluded that **publication bias could have influenced the size of the true effect, but it could not have affected the general conclusion** (i.e. that a positive association exists).

Conclusions

Orellano and fellow researchers concluded that an increase in short-term exposure to PM_{10}, $PM_{2.5}$, NO_2 and O_3 increased the risk of all-cause mortality in people. They also concluded that an increase in daily concentrations of PM_{10} and $PM_{2.5}$ increased the risk of cause-specific mortality in people (specifically, cardiovascular, respiratory and cerebrovascular mortality).

[2] For more information on this systematic review, refer "Effects of short-term exposure to NO_2, O_3 and SO_2 on asthma" (Wickham *et al.* 2022b).

The concentration response functions for PM were generally linear and did not detect a threshold. The concentration response function for NO_2 associated with daily exposure showed some evidence of a threshold, in line with previous estimates.

These results were robust through several sensitivity analyses. The high consistency in the direction of the associations, and the high or moderate certainty of evidence reinforce the hypothesis of a positive association between air pollution and human mortality.

WHO Short-Term PM, NO_2 & O_3 Guidelines

Short-term ambient air quality guidelines (AQG) for NO_2 and O_3 were set to protect against *inter alia* increased respiratory hospital admissions for asthmatics (WHO 2000). The WHO 2005 short-term AQG for $PM_{2.5}$ and PM_{10} were based on the epidemiology of short-term exposure of PM with all-cause mortality (WHO 2006).

The 24-hour AQG for PM, NO_2 and O_3 were updated in 2021 based on new evaluations of the epidemiology of short-term exposure of with all-cause mortality (Orellano *et al.* 2020) as well as a new evaluation of the epidemiology of short-term exposure with emergency room visits and hospitalisations for asthmatics (Zheng *et al*. 2021).[2] Existing guidelines remain valid (WHO 2021).

It is important to note that the approach to setting guidelines does not identify safe levels and is not based on a defined level of acceptable risk (i.e., the guidelines are not "no adverse effect levels").

Pollutant / Time Average	Guideline (µg/m^3)	Permitted Exceedances per year
$PM_{2.5}$		
24-hours	15	3-4
PM_{10}		
24-hours	45	3-4
NO_2		
24-hours	25	3-4
1-hour	200	–
O_3		
8-hour daily maximum	100	3-4

References

Beverland, I.J., Cohen, G.R., Heal, M.R., Carder, M., Yap, C., Robertson, C., Hart, C.L. and Agius, R.M., 2012. A Comparison of Short-term and Long-term Air Pollution Exposure Associations with Mortality in Two Cohorts in Scotland. *Environ. Health Perspect*. 120, 1280–1285. doi.org/10.1289/ehp.1104509

Orellano P., Reynoso J., Quaranta N., Bardach A., Ciapponi A., 2020. Short-Term exposure to particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3) and all-cause and cause-specific mortality: Systematic review and meta-analysis. *Env Int*. Vol 142. September 2020. 105876. doi.org/10.1016/j.envint.2020.105876

Moolgavkar, S.H., McClellan, R.O., Dewanji, A., Turim, J., Luebeck, E.G., Edwards, M., 2013. Time-series analyses of air pollution and mortality in the United States: a subsampling approach. *Environ. Health Perspect*. 121, 73–78. doi.org/10.1289/ehp.1104507

Pope, C.A., 2007. Mortality effects of longer term exposures to fine particulate air pollution: review of recent epidemiological evidence. *Inhal. Toxicol*. 19 (Suppl 1), 33–38. doi.org/10.1080/08958370701492961.

Wickham L., Cridge B., Nicoll R., Powell J., 2022a. *Health Effects of Air Pollutant Factsheets: Supporting Information.* Factsheet prepared by Emission Impossible Ltd and ESR for Ministry of Health. October. [Online: www.esr.cri.nz]

Wickham L., Cridge B., Nicoll R., Powell J., 2021b. *Effects of short-term exposure to NO_2, O_3 and SO_2 on asthma.* Factsheet prepared by Emission Impossible Ltd and ESR for Ministry of Health. October. [Online: www.esr.cri.nz]

World Health Organisation (WHO), 2006. *Air Quality Guidelines Global Update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide*. WHO Regional Office for Europe. Copenhagen. Denmark. [Online: www.euro.who.int]

WHO, 2020. *Risk of bias assessment instrument for systematic reviews informing WHO global air quality guidelines*. WHO Regional Office for Europe. Copenhagen. Denmark. [Online: www.who.int]

WHO, 2021. *WHO global air quality guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. Geneva. [Online: www.who.int]

Zheng Xue-yan., Orellano Pablo, Lin Hua-liang, Jiang Mei, Guan Wei-jie, 2021. Short-term exposure to ozone, nitrogen dioxide, and sulphur dioxide and emergency department visits and hospital admissions due to asthma. A systematic review and meta-analysis. *Env Int*. Vol 150. February. 106435. doi.org/10.1016/j.envint.2021.106435