5 Stuckler D, Meissner C, Fishback P, Basu S, McKee M. Banking crises and mortality during the Great Depression: evidence from US urban populations, 1929–1937. *J Epidemiol Community Health* 2012; **66:** 410–19.

6 Ramsey S, Blough D, Kirchhoff A, et al. Washington State cancer patients found to be at greater risk for bankruptcy than people without a cancer diagnosis. *Health Aff (Millwood)* 2013; **32:** 1143–52.

7 Beckmann KR, Bennett A, Young GP, et al. Sociodemographic disparities in survival from colorectal cancer in South Australia: a population-wide data linkage study. *BMC Health Serv Res* 2016; **16:** 24.

8 Eloranta S, Lambert PC, Cavalli-Bjorkman N, Andersson TM, Glimelius B, Dickman PW. Does socioeconomic status influence the prospect of cure from colon cancer—a population-based study in Sweden 1965–2000. *Eur J Cancer* 2010; **46:** 2965–72.

9 Tehranifar P, Neugut AI, Phelan JC, et al. Medical advances and racial/ethnic disparities in cancer survival. *Cancer Epidemiol Biomarkers Prev* 2009; **18:** 2701–08.

10 Shortell SM, McCurdy RK. Integrated health systems. *Stud Health Technol Inform* 2010; **153:** 369–82.

11 Rhoads KF, Patel MI, Ma Y, Schmidt LA. How do integrated health care systems address racial and ethnic disparities in colon cancer? *J Clin Oncol* 2015; **33:** 854–60.

12 IOM. Delivering high-quality cancer care: charting a new course for a system in crisis. Washington, DC: Institute of Medicine, 2013.


# Air pollution and heart disease

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In *The Lancet*, Joel Kaufman and colleagues[1] report an association between various metrics of long-term air pollution exposure and progression of coronary artery calcification (CAC), a strong risk marker of future ischaemic vascular events. Over 10 years, the investigators did repeated CAC measurements on a population of almost 7000 people living in different metropolitan areas of the USA, making this the largest study of its kind. Long-term average concentrations of fine particulate matter less than 2·5 μm in diameter ($PM_{2.5}$) in the participants ranged from 9·2–22·6 μg/m³. The average rate of CAC progression was 24 Agatston units per year across all participants, and the rate of CAC progression was accelerated by 4·1 Agatston units per year (95% CI 1·4–6·8) for every 5 μg $PM_{2.5}$/m³. This finding suggests that—all other things equal—moving from a residence with 11 μg $PM_{2.5}$/m³ annual average exposure (such as that measured in 2013 at the rural Bois-Herpin station 60 km south of Paris) to one with 22 μg $PM_{2.5}$/m³ concentrations (such as at the near-road station in Saint Mande, Paris), would result in about 38% faster annual progression of atherosclerosis (pollution measurements as reported by the European Environment Agency for 2013). Kaufman and colleagues' study[1] is exemplary in its prospective design, detailed air pollution exposure assessment, meticulous measurements of CAC progression, and its comprehensive approach to analysis.

For more on the **European Environment Agency for 2013** see http://www.eea.europa.eu/themes/air/interactive/pm2_5

The association between fine particulate matter and cardiovascular disease outcomes has been documented in many studies including multicentre studies.[2] Few studies, however, have been able to directly study subclinical markers of atherosclerosis, the underlying pathology for most cardiovascular disease (such as CAC) or intima media thickness (IMT). Kaufman and colleagues' study looked at the progression of these two subclinical markers over time, but found associations between air pollutants and CAC only. After initial enthusiasm,[3] subsequent studies have not been able to provide consistent evidence for an association of IMT progression with air pollution,[4] nor of a clear association between IMT progression and incident cardiovascular disease events.[5] Kaufman and colleagues argue that the inherently large measurement error relative to the potential air pollution-related change over time makes this marker difficult to study. Because CAC is a stronger predictor of cardiovascular events than IMT anyway, further studies looking at CAC as an outcome are especially relevant.

One of the strengths of the present study is the detailed exposure assessment, based on dedicated monitoring campaigns and advanced spatio-temporal modelling. As the authors show in table 6 of the appendix, this effort was worth it, because $PM_{2.5}$ exposure estimated from just the regulatory air pollution monitor closest to the home was less strongly associated with CAC progression—4·1 Agatston units per year (1·4–6·8) per 5 μg/m³ at an individual's home compared with 2·9 (–0·1 to 6·8) units per year as measured at the nearest regulatory monitor.

By investigating several pollutants, inferences were also possible about which pollutants matter most. By and large, associations were strongest for $PM_{2.5}$ and nitrogen oxides ($NO_x$). $PM_{2.5}$ is a mixture of primary and secondary pollutants with large contributions from sulphates, nitrates, and ammonium formed by atmospheric reactions of precursor gases mainly from

industry, traffic, and agriculture. $NO_x$ is seen mostly as a marker for more locally generated traffic pollution mixtures. So the results suggest to us that both locally generated and secondary pollutants are important. Unfortunately, the two pollutants were too highly correlated at 0·87 to separate their effects in a two-pollutant model. Another marker of traffic pollution used was black carbon. Associations between CAC and black carbon would have been expected to mirror those with $NO_x$, but associations with black carbon were consistently null, despite a very high correlation of 0·90 with $NO_x$. Perhaps, black carbon concentrations in this study were less representative of harmful components of the traffic pollution mixture in view of the very low penetration of diesel powered passenger cars in the USA, compared with most of Europe, where black carbon is considered a good marker for high traffic exposure.[6] Indeed, in a large European study,[7,8] black carbon concentrations were considerably higher than in the Kaufman study, whereas $NO_x$ concentrations were not.

The evidence for the harmful effects of ambient air pollution on progression of atherosclerosis is also supported by the analogy with environmental tobacco smoke.[9] Environmental tobacco smoke resembles, in many aspects, ambient air pollution in its richness in fine and ultrafine particulate matter and its content of combustion products. Environmental tobacco smoke is associated with cardiovascular events,[10] and evidence also suggests an association of environmental tobacco smoke with CAC.[11]

A final point concerns the concentration-response function elegantly displayed in figure 3 of Kaufman and colleagues' study. There was no sign of a threshold below which effects of $PM_{2.5}$ on CAC do not occur. This is sobering, considering that the $PM_{2.5}$ concentrations in many European cities—let alone most other, more polluted cities in the world, many of which show increasing concentrations[12]—are actually higher than those reported by Kaufman and colleagues, probably because the annual EU limit value for $PM_{2.5}$ sits at 25 μg/m³, which is twice higher than the US Environmental Protection Agency Annual National Ambient Air Quality Standard of 12 μg/m³ and 2·5 times higher than the WHO Air Quality Guideline (AQG) of 10 μg/m³. This latter value was set in 2005 and will be revised in the next few years. In view of emerging evidence of effects of $PM_{2.5}$ on cardiovascular mortality at concentrations well below the current WHO AQG,[13] the new AQG is likely to move down rather than up. Yet, European policy makers seem to be dragging their feet when it comes to taking decisive action against one of the biggest environmental health threats we face today.[14] How much more evidence do they need before coming up with a serious remedy?

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1 Kaufman JD, Adar SD, Barr RG, et al. Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. *Lancet* 2016; published online May 24. http://dx.doi.org/10.1016/S0140-6736(16)00378-0.
2 Hoek G, Krishnan RM, Beelen R, et al. Long-term air pollution exposure and cardio-respiratory mortality: a review. *Environ Health* 2013; **12:** 23.
3 Kunzli N, Perez L, von Klot S, et al. Investigating air pollution and atherosclerosis in humans: concepts and outlook. *Prog Cardiovasc Dis* 2011; **53:** 334–43.
4 Perez L, Wolf K, Hennig F, et al. Air pollution and atherosclerosis: a cross-sectional analysis of four european cohort studies in the ESCAPE Study. *Environ Health Perspect* 2015; **123:** 597–605.
5 Lorenz MW, Polak JF, Kavousi M, et al. Carotid intima-media thickness progression to predict cardiovascular events in the general population (the PROG-IMT collaborative project): a meta-analysis of individual participant data. *Lancet* 2012; **379:** 2053–62.
6 Janssen NAH, Hoek G, Simic-Lawson M, et al. Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM10 and $PM_{2.5}$. *Environ Health Perspect* 2011; **119:** 1691–99.

7 Cyrys J, Eeftens M, Heinrich J, et al. Variation of NO2 and NOx concentrations between and within 36 European study areas: results from the ESCAPE study. *Atmos Environ* 2012: **62:** 374–90.

8 Eeftens M, Tsai M-Y, Ampe C, et al. Spatial variation of $PM_{2.5}$, PM10, $PM_{2.5}$ absorbance and PMcoarse concentrations between and within 20 European study areas and the relationship with NO2—results of the ESCAPE project. *Atmos Environ* 2012: **62:** 303–17.

9 Pope CA 3rd, Burnett RT, Turner MC, et al. Lung cancer and cardiovascular disease mortality associated with ambient air pollution and cigarette smoke: shape of the exposure-response relationships. *Environ Health Perspect* 2011; **119:** 1616–21.

10 Dunbar A, Gotsis W, Frishman W. Second-hand tobacco smoke and cardiovascular disease risk an epidemiological review. *Cardiol Rev* 2013: **21:** 94–100.

11. Peinemann F, Moebus S, Dragano N, et al. Secondhand smoke exposure and coronary artery calcification among nonsmoking participants of a population-based cohort. *Environ Health Perspect* 2011: **119:** 1556–61.

12 WHO. WHO Global Urban Ambient Air Pollution Database (update 2016). 2016. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ (accessed May 19, 2016).

13 Thurston GD, Ahn J, Cromar KR, et al. Ambient particulate matter air pollution exposure and mortality in the NIH-AARP diet and health cohort. *Environ Health Perspect* 2016; **124:** 484–90.

14 Brunekreef B, Kuenzli N, Pekkanen J, et al. Clean air in Europe: beyond the horizon? *Eur Respir J* 2015: **45:** 861–61.


# The last Summer Olympics? Climate change, health, and work outdoors

Climate change threatens human health in many ways, through heat waves, extreme weather events, and shifts in disease vectors, as well as economic and social stresses on populations living in or trying to escape areas affected by seawater intrusion, drought, lower agricultural productivity, and floods.[1] In the short term, most of these impacts could be substantially ameliorated by actions to reduce background disease risks and other known causes of vulnerability. The world beyond 2050 poses increasingly difficult challenges, not only because of the inherent uncertainties in long-term predictions, but because the extent and speed of change might exceed society's ability to adapt.[2] In addition, the risk of so-called pernicious impacts—those that require trade-offs between what is generally assumed and valued as part of society and what is healthy—will rise.

Perhaps the most pernicious of these impacts is the growing expansion in season and geography of outdoor conditions (or unprotected indoor spaces) in which heavy work is no longer safe. Because more than half the planet's workforce works outdoors, primarily in construction and agriculture, society faces an increasingly serious trade-off between population health and labour productivity.[3] The risk to workers' health could be minimised if workers are allowed to sit in the shade during the hottest times of day and take breaks during hot, humid months. Otherwise, exertional heat stroke and its negative outcomes, including mortality, will become a large part of outdoor work around the world.[4] Increasingly, people will face a choice between doing what they have done for millions of years—work hard outdoors essentially any time they wish—and being safe.[5]

Heavy work outdoors is already limited in some parts of the world by heat stress—as measured by the wet-bulb globe temperature (WBGT), a combination of temperature, humidity, heat radiation, and wind—and climate change means more regions will be affected for a greater part of the year.[6]

Athletes are especially prone to heat stress in outdoor endurance events, as shown in the 2007 Chicago Marathon, which was cancelled mid-race after hundreds of heat-stricken runners required medical care.[7] In 2016, only about 70% of the elite competitors in the US Olympic Team Trials Marathon in Los Angeles finished,[8] in a race where peak temperature reached 25·6°C.[10]

The Summer Olympics represent only a small part of all outdoor work, but are iconic as the most prestigious and inclusive sporting competition in the world. Using the mean of two standard climate models, we made projections of rising temperature and humidity over the next century, assuming the high emissions RCP8·5 scenario,[11] and estimated the effects on the number and global distribution of cities eligible to host the Summer Olympic Games.

We focused only on the northern hemisphere, which contains nearly 90% of world population and allows a consistent and customary definition of summer as July to August—noting this period is not always the hottest in some countries such as India. We only included cities over 600 000 population in 2012—the lower limit among host cities since World War 2—reflecting the massive expectations in logistics and financing required