CG. Report 4: Effects of COVID-19 Restrictions on Air Pollution

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Summary

Reductions in the movement of people and industrial production during COVID restrictions resulted in lower levels of particulate matter (PM) of all sizes, Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2) and Carbon Monoxide (CO), pollutants that are associated with increased mortality. However, the window of observation of most studies ended in the late spring of 2020. Therefore, it is unclear whether lowering pollutant levels were sufficiently long to affect morbidity and mortality. In addition, studies indicated a return to pre-restriction levels shortly after restrictions were lifted.

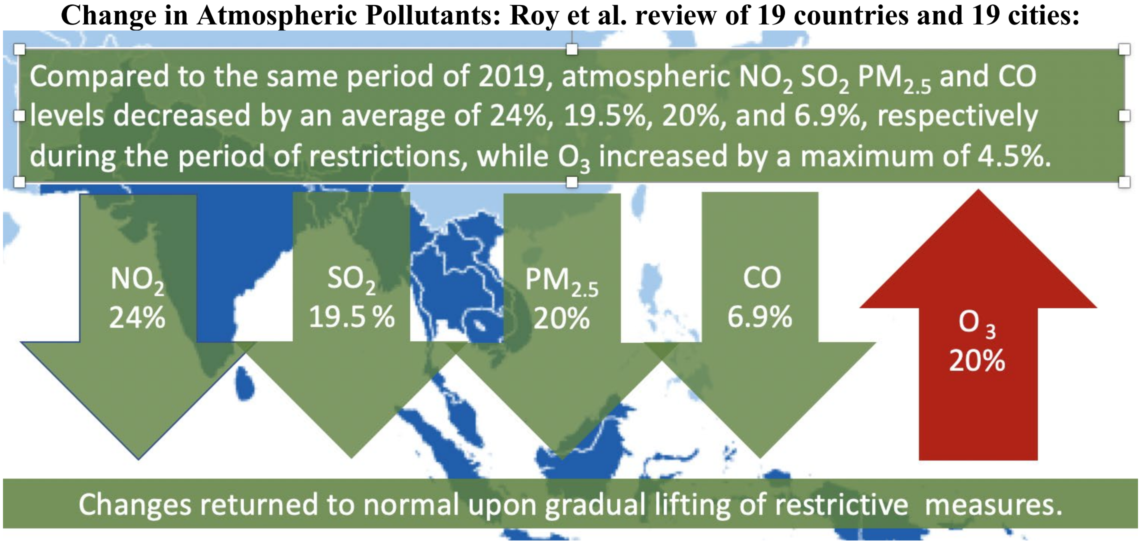
The quality of the evidence was judged to be moderate: future high-quality longitudinal studies are required to assess the long term sustainability of measures to reduce pollution independently from the imposition of restrictions.

The impact of COVID-19 restrictions on the global levels of environmental pollutants is likely to be beneficial. Lower levels of pollution observed during restrictions provide estimates for attainable pollutants that can benefit health and wellbeing.

Main Recommendations

The beneficial effects of improved ambient air quality should be followed with long term longitudinal studies assessing whether the improvements are sustainable along with the repercussions on mortality, respiratory and cardiovascular pathologies. Changes in work patterns should be monitored to evaluate their impact on pollution levels.

Change in Atmospheric Pollutants: Roy et al. review of 19 countries and 19 cities:



Introduction

Exposure to high levels of air pollutants causes a variety of adverse health outcomes. [1] Global industrial growth led to significant rises in air pollutants. Consequently, many countries passed legislation to establish clean air, but problems with air pollution persist.

The tiny particulate matter that remains in the atmosphere is one of the most dangerous and widespread pollutants; it is typically emitted by diesel exhaust and when gas, oil and other fossil fuels are burned. Particles less than 10 micrometres in diameter (PM_{10}) can be inhaled and accumulate in the respiratory system. Particles less than 2.5 micrometres ($PM_{2.5}$) pose a greater risk as they lodge deep in the lungs; they are most hazardous in vulnerable populations: children, older adults and those with pre-existing health conditions.

Ambient outdoor air pollution causes substantial harm. [2] In less developed countries, 98% of children under five breathe toxic air. In 2019, Bangladesh was the most polluted country for $PM_{2.5}$ exposure, with Pakistan, Mongolia, Afghanistan and India just behind. Mainland China was 11th in the 2019 ranking with an average $PM_{2.5}$ concentration of 39.1 $\mu g/m^3$, over four times the U.S. average of 9.0 $\mu g/m^3$. [3]

Pollution is a complex microscopic cocktail of chemicals that, at high levels, can cause serious adverse outcomes. For example, Nitrogen dioxide (NO_2), mainly produced during the combustion of fossil fuels, gives rise to airway inflammation and susceptibility to respiratory infections. The WHO Global Air Quality guidelines set thresholds and limits for the air pollutants that pose significant health risks. These include particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2).

COVID-19 restrictions will likely affect pollutant levels creating a unique opportunity to study the impact on air quality. Global road transport activity was nearly 50% below the 2019 average by the end of March 2020; countries in total lockdown experienced an average 25% decline in energy demand per week, and those in partial lockdown an average 18% decline. [4] We set out to synthesize the published systematic review evidence of the effects of global restrictions on ambient air pollutant levels.

Methods

We performed a scoping review using a flexible framework for restricted systematic reviews. [5]. We Searched LitCovid, and the WHO COVID-19 database using the search terms (“pollution” OR "air quality" OR “NO2” OR "particulate matter" OR “atmosphere”) AND "systematic review" We searched the bibliographies of retrieved articles for systematic review articles. We also included reports by national or international agencies that included original data on ambient air pollution.

We extracted data on the number of included studies, the methods including the study types, the search dates and any quality assessment. We tabulated the data and summarised the main findings and the quality of the evidence. Our review approach is available on the Collateral Global website: What is a Rapid Review? [6]

Quality

All studies were ecological before and after design. The observed effect sizes represent potent indicators of a real gain in air quality as their results are univocal. However, the lack of mapping of restrictions and their chronology of introduction makes the assessment of the advantages on pollution levels of different types of restrictions and their time windows impossible.

Results

We identified 4,743 records (WHO, 3013; Lit Covid, 1721). Of these, we assessed 125 records for eligibility. For the impact assessment, we included three reviews (see Table 1 characteristics) and four NGO reports (see Figure 2).

Impact

The studies show a consistent decrease in PM, NO_2, SO_2 and CO compared to the same period in previous years. These falls were usually accompanied by a rise in ozone levels, possibly because of more photosynthesis because of the absence of U.V. block. Overall we rated the impact on pollution as substantial based on the following main findings.

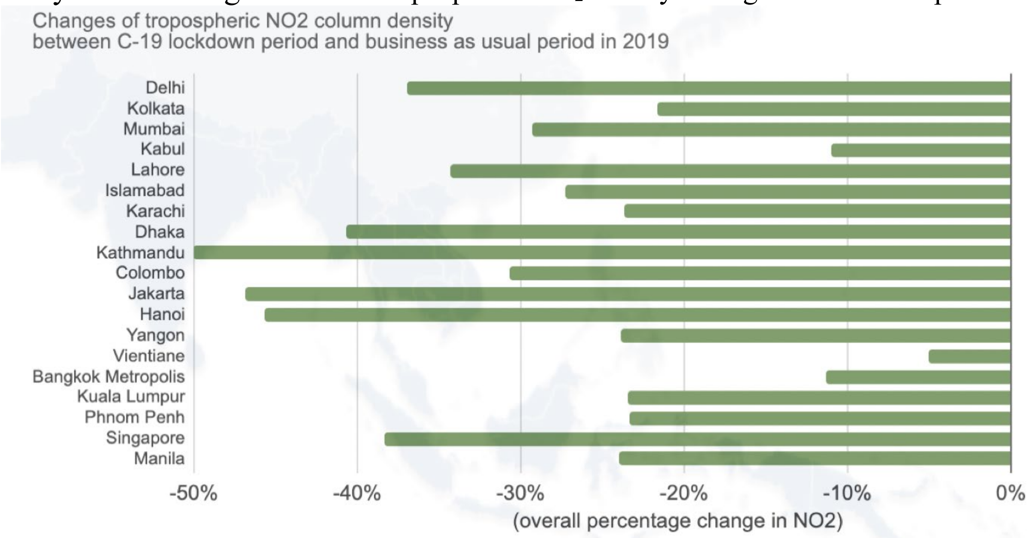
Roy's review of 19 countries and 19 cities in South and Southeast Asia used satellite-based estimations of air pollutants over two covid restrictions phases (March 27 to May 31 2020) and compared them with a "Business as Usual" (BAU) period in 2019. [Roy 7]

A maximum overall reduction in atmospheric NO_2 density was observed in Hanoi, Dhaka, Karachi, Mumbai, and Colombo compared to pre-lockdown. Countries that enforced tighter restrictions correlated with higher reductions in atmospheric NO_2 levels.

Eight cities experienced a greater than 30% fall in the mean tropospheric NO_2 density during the COVID-19 restriction periods. These cities closed industrial and processing activities, suspended all modes of international and inter-district transportations and imposed stay-at-home orders (See Figure 1).

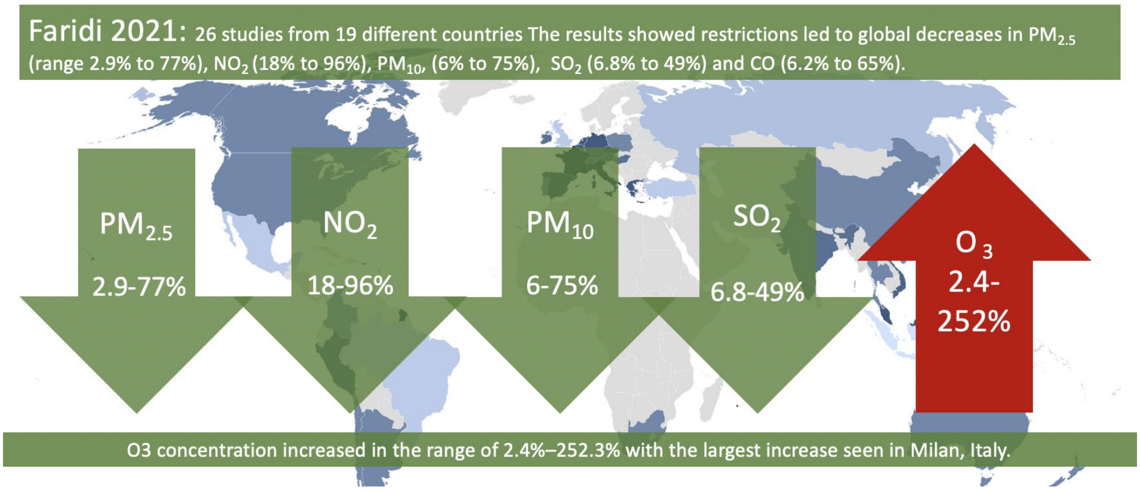
Changes returned to baseline with the gradual lifting of restrictions. For example, atmospheric NO_2 increased from the end of April 2020 in most cities in Bangladesh, India, and Pakistan despite strict lockdown measures continuing till the end of May.

Figure 1: Roy 2021. Changes in mean tropospheric NO_2 density during the restriction period.



A second review [Faridi 2021], including 26 studies from 19 countries, compared human mobility and ambient air quality with pollutants before and after restrictions were imposed or with the same period in 2019. [8] The results showed restrictions led to global decreases in $PM_{2.5}$ (range 2.9% to 77%), NO_2 (18% to 96%), PM_{10}, (6% to 75%), SO_2 (6.8% to 49%) and CO (6.2% to 65%). Similar to the finding of Roy's review, O_3 concentration increased by 2.4% to 252% (see Figure 2).

Figure 2: Faridi 2021. Changes in ambient air quality during the restriction period.



A third review [Rana 2021] synthesized evidence from 35 studies of restrictions on air quality in China. The review reported that China's urban, industrial, and highly populated areas experienced more significant improvements in air quality than rural, residential and less populated areas. [9] The Hubei province and Wuhan experienced the most rapid decreases in pollution levels. Despite the changes, the pollutant concentrations in many regions exceeded the World Health Organization's guidelines (e.g., Beijing, where $PM_{2.5}$ and PM_{10} levels remained above 100 µg/m^3).

Table 1: Systematic review characteristics

Study Identifier and Aim	Countries or Regions	Type of Evidence
Roy 2021 **19 countries - 19 selected cities** Geospatial analysis of COVID-19 lockdown effects on air quality in the South and Southeast Asian region	**Countries:** Afghanistan, Bangladesh, Maldives, Singapore, Nepal, Pakistan, Myanmar, Sri Lanka, Vietnam, Thailand, India, Philippines, Laos, Vietnam, Indonesia, Brunei, Bhutan, Timor, Malaysia - **Cities**: Delhi Kolkata, Mumbai, Kabul, Lahore, Islamabad, Karachi, Dhaka, Kathmandu, Colombo, Jakarta, Hanoi, Yangon, Vientiane, Bangkok Metropolis, Kuala Lumpur, Phnom Penh, Singapore, Manila	Review of timing and type of lockdown measures based on governmental and regional directives and media reports. Identification of date of first C19 cases reported and periods of observation - two temporal frames over 66 days (March 27 to May 31 2020). Satellite-based estimations of air pollutants and comparison between "Business as Usual" (BAU) level of pollutants and end period of observation and analysis. Pollutants levels (NO2, SO2, CO, PM2.5, and O3 in the atmosphere) were assessed from a mixture of satellite-derived evidence and wind speed estimation.
Faridi 2021 **26 studies from 19 different countries** Analysis of the effect of COVID-19 pandemic on human mobility and ambient air quality.	China, Malaysia, India, United Arab Emirates (UAE), Kazakhstan, Singapore, Thailand, Vietnam, Indonesia, Philippines, Cambodia, Laos, Myanmar, Brazil (4 studies), Italy, Spain, France, Morocco. Five other studies were conducted in more than one continent (two in Asia and Europe, two in Asia, Europe, and Northern America (USA)	Review of restriction mapping from 25 primary studies by type and phase of implementation. All studies compared the concentration of pollutants before and after restrictions (approximately 60% of studies) or with the same period in 2019 (40%). Pollution levels were either measured directly on the ground or inferred from satellite images. Ambient air pollutants changes in PM2.5, PM10, NO2, NOX, NO, O3, SO2, CO, black carbon, BTEX (benzene, toluene, ethylbenzene, o-Xylene), NH3, and non-methane hydrocarbons (NMHC) were investigated, two studies reported the changes in Aerosol Optical Depth (AOD) and five studies reported the air quality index (AQI)
Rana 2021 **35 Studies** The Impact of COVID-19 Lockdowns on Air Quality	China	Original studies measuring NO2, PM2.5, PM10, SO2, CO, O3 and air quality index (AQI) in at least one Chinese city or province. Pollution levels were assessed using satellite pictures (n=12) or ground sampling (n=23).

Reports

NASA Reports
A 2020 NASA report found that pandemic restrictions have reduced global NO_2 concentrations by nearly 20% since February. A second NASA study reported modest effects on $PM_{2.5}$ using a combination of spacecraft data with ground-based monitoring and computer modelling to map levels in China, Europe and North America in January to April of 2018, 2019 and 2020. Changes were difficult to detect in areas other than China, possibly due to the high background level of pollution. NASA inferred that seasonal differences in $PM_{2.5}$ were likely to be driven by natural variability in meteorology instead of pandemic restrictions.

Centre for Cities
A 2020 analysis by the Centre for Cities reported that air pollution in cities fell over the course of the first UK national lockdown. Still, post restrictions pollution met or exceeded pre-pandemic levels in 80 per cent of places studied. The study assessed NO_2 and $PM_{2.5}$ and compared data from 49 cities or conurbations for the end of March and mid-May 2019 and 2020. In cities and large towns, NO_2 concentration levels more than halved during the lockdown, but not all cities and large towns experienced a significant improvement in air quality. When restrictions were lifted, air pollution returned to its pre-pandemic levels in 39 (80%) of the cities and large towns studied, even though none had returned to previous levels of economic activity.

World Bank
The World Bank analysed the impact of the lockdown on air quality. Satellite imaging comparison based on estimation of NO_2 concentration between March 15 and April 30, 2020 (with lockdown) and the same period of 2019 was augmented with ground station measurements of $PM_{2.5}$. The analysis found a significant impact on NO2 reductions but not with $PM_{2.5}$, which they consider explained by seasonal variations.

World Meteorological Organization (WMO)
The WMO reported on the air quality and climate of 63 cities in 25 countries. The survey analysed six different pollutant levels from January to September 2015 to 2019 with the same period in 2020. Data from air sampling and ground stations reported decreases up to 70% in mean NO_2 levels and 30% to 40% in mean $PM_{2.5}$ concentrations during the full lockdown periods.

The report highlighted that $PM_{2.5}$ has complex dispersion patterns that can be affected by long-range transport of dust and/or biomass burning and secondary PM formation. For example, in 2020, wildfires generated anomalously high $PM_{2.5}$ in several arid and hot regions.

Ozone concentrations showed small increases or no increase in Europe, larger increases in East Asia and South America. As a result, SO_2 concentrations were between 25% to 60% lower in 2020 for all regions, as were CO levels, with the most prominent decrease observed in South America (up to 40%).

Discussion
We identified a robust evidence base with observations from countries spanning most of the globe. Ecological studies are hugely powerful but can be prone to bias. In the case of repeated observations by different agencies covering most of the earth's population, such biases are unlikely to distort the results. In terms of causation, consistency of results is upheld when multiple epidemiologic studies using a variety of locations report similar findings.

Restrictions on movement, activity and industrial production caused a dramatic increase in the quality of the air. Although perhaps too brief to show an effect on overall morbidity and mortality, the effects on health are uncertain but potentially large. A significant body of evidence from systematic reviews shows long term air pollutants are associated with substantial wide-ranging adverse health effects, including increased mortality. Furthermore, high-quality evidence also indicates that short term exposure to many pollutants increases morbidity and mortality. (See Table 2)

The reasons for the increase in O_3 are unclear. Explanations included the decreased emission of NO_2 in the volatile organic carbon-limited-limited environment and increased O_3 in the lower atmosphere. Other studies suggested reductions in $PM_{2.5}$ and NO_2 increased solar radiation and accelerated photochemical reactions that produced extra O_3 in the lower atmosphere.

The effects of restrictions on ambient air pollutants were heterogeneous across countries and within countries. Part of the reason is the substantial variation in pre-pandemic levels of pollutants, large-scale urbanization and economic development in low and middle-income countries (LMICs), which led to significant disparities in air pollution exposure. Every year, air pollution is estimated to cause 7 million premature deaths. [11]

The limits of this review are the absence of sufficient detail in the primary studies to enable assessment of the link between pollution and a particular type of restriction and, in parallel, the use of the general term "lockdown" in all studies except one without a detailed implementation timeline or explanation of the type of restrictions imposed.

Recommendations

The beneficial effects on pollution levels of the introduction of restrictions to limit pandemic spread should be followed with long term longitudinal studies assessing whether the improvement in air quality was sustained and its repercussions on mortality, respiratory and cardiovascular pathologies. Changes in work patterns should be monitored to evaluate their impact on pollution levels. As COVID-19 is a global problem, so is air pollution. Therefore, the falls in air pollutants observed in the COVID-19 restrictive phases should be investigated more thoroughly. A globally coordinated sustainable strategy is therefore essential to decrease pollution levels while maintaining growth and economic activity.

Table 2. Systematic Reviews of the Impact of pollutants on morbidity and mortality

Study ID & pollutant	Review Aim and number of studies	Findings: Hazard Ratios (H.R.); Relative Risks (R.R.)
Stieb 2021 [11] **NO_2**	Long term outdoor nitrogen dioxide exposure and mortality 79 studies (47 cohorts, plus one pooled analysis of multiple European cohorts).	Pooled H.R. indicated that long term exposure to **NO_2** was significantly associated with mortality from all/ natural causes, pooled H.R. 1.047 (95% CI, 1.023-1.072 per 10 ppb) and cardiovascular disease, H.R. 1.058 (1.026-1.091); lung cancer H.R. 1.083 (1.041-1.126); respiratory disease H.R. 1.062 (1.035-1.089) and ischemic heart disease H.R. 1.11 (1.079-1.14)
Orellano 2021 [12] **SO_2**	Short-term exposure to sulphur dioxide (SO_2) and all-cause and respiratory mortality 67 studies.	An increment of 10 µg/m3 in **SO_2** (24-hour average) was associated with all-cause mortality, R.R.: 1.0059 (95% CI: 1.0046-1.0071), and respiratory mortality, R.R.: 1.0067 (1.0025-1.0109). Associations were still significant after adjustment for PM, but not for other pollutants (13 studies).

Zheng 2021 [13] **NO_2, SO_2 & O_3**	Short-term exposure to O_3, NO_2, and SO_2 & emergency department visits & hospital admissions due to asthma: 67 studies (48 children, 21 adults, 14 elderly & 31 general population).	R.R. per 10 µg/m3 increase of ambient concentrations in asthma Emergency Room visits and Hospital Admissions **O_3** hour daily or average 24-hour R.R.=1.008 (95% CI: 1.005, 1.011) **NO_2** 24-hour average R.R.=1.014 (1.008, 1.020) **SO_2** 24-hour average R.R.=1.010 (1.001, 1.020)
Niu 2021 [14] **$PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3**	Association between exposure to ambient air pollution and hospital admission, incidence, and mortality of stroke 68 studies (more than 23 million participants)	Associations of six air pollutants with stroke hospital admission: **$PM_{2.5}$** OR = 1.008 (95% CI 1.005, 1.011); **NO_2** OR = 1.023 (1.015, 1.030), per 10 µg/m3 increase. Increased risks of stroke incidence: **$PM_{2.5}$** H.R. = 1.048 (1.020, 1.076); **SO_2** H.R. = 1.002 (1.000, 1.003); **NO_2** H.R. = 1.002 (1.000, 1.003). No significant differences for PM_{10}, CO, O_3, and stroke incidence. Higher levels of $PM_{2.5}$, PM_{10}, SO_2, and NO_2 exposure associated with higher stroke mortality **PM_{10}** OR = 1.006 (1.003, 1.010); **SO_2** OR = 1.006 (1.005, 1.008).
Atkinson 2014 [15] **$PM_{2.5}$**	Epidemiological time-series studies of $PM_{2.5}$ and daily mortality and hospital admissions 110 studies	All-cause mortality: **$PM_{2.5}$** 10 µg/m3 increment: 1.04% (95% CI 0.52% to 1.56%) increase in the risk of death. Associations for respiratory causes of death were larger than for cardiovascular causes, 1.51% (1.01% to 2.01%) vs 0.84% (0.41% to 1.28%).

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Ethics Committee Approval
No approval was necessary.

Data Availability
All data included in the review are provided in the tables.

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This review received funding from Collateral Global.

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Tables and Figures

Table 1: Systematic review characteristics
Table 2. Systematic reviews of the impact of ollutants on morbidity and mortality

Figure 1: Roy 2021. Changes in mean tropospheric NO_2 density during the restriction period.
Figure 2: Faridi 2021. Changes in ambient air quality during the restriction period.

Competing Interest Statement
T.J. received a Cochrane Methods Innovations Fund grant to develop guidance on using regulatory data in Cochrane reviews (2015 to 2018). From 2014 to 2016, he was a member of three advisory boards for Boehringer Ingelheim. Market research companies occasionally interview T.J. about phase I or II pharmaceutical products for which he receives fees (current). TJ was a member of three advisory boards for Boehringer Ingelheim (2014 to 16). TJ was a member of an independent data monitoring committee for a Sanofi Pasteur clinical trial on an influenza vaccine (2015 to 2017). TJ is a relator in a False Claims Act lawsuit on behalf of the United States that involves sales of Tamiflu for pandemic stockpiling. If resolved in the United States favour, he would be entitled to a percentage of the recovery. T.J. is coholder of a Laura and John Arnold Foundation grant to develop a RIAT support centre (2017 to 2020) and Jean Monnet Network Grant, 2017 to 2020 for The Jean Monnet Health Law and Policy Network. TJ is an unpaid collaborator to the Beyond Transparency in Pharmaceutical Research and Regulation led by Dalhousie University and

funded by the Canadian Institutes of Health Research (2018 to 2022). T.J. consulted for Illumina LLC on next-generation gene sequencing (2019 to 2020). TJ was the consultant scientific coordinator for the HTA Medical Technology programme of the Agenzia per i Servizi Sanitari Nazionali (AGENAS) of the Italian MoH (2007 to 2019). T.J. is Director Medical Affairs for B.C. Solutions, a market access company for medical devices in Europe. T.J. was funded by NIHR UK and the World Health Organization (WHO) to update Cochrane review A122, Physical Interventions to interrupt the spread of respiratory viruses. Oxford University funds T.J. to carry out a living review on the transmission epidemiology of COVID 19. Since 2020, T.J. has received fees for articles published by The Spectator and other media outlets. T.J. is part of a review group carrying out a Living rapid literature review on the modes of transmission of SARS CoV 2 (WHO Registration 2020/1077093 0). He is a member of the WHO COVID 19 Infection Prevention and Control Research Working Group, for which he receives no funds. T.J. is funded to co-author rapid reviews on the impact of Covid restrictions by the Collateral Global Organisation. CJH holds grant funding from the NIHR, the NIHR School of Primary Care Research, the NIHR BRC Oxford and the World Health Organization for a series of Living rapid reviews on the modes of transmission of SARs-CoV-2 reference WHO registration No2020/1077093. He has received financial remuneration from an asbestos case and legal advice on mesh and hormone pregnancy tests cases. He has received expenses and fees for his media work, including periodic payments from BBC Radio 4 Inside Health and The Spectator. He receives expenses for teaching EBM and is also paid for his G.P. work in NHS out of hours (contract Oxford Health NHS Foundation Trust). He has also received income from publishing a series of toolkit books and appraising treatment recommendations in non-NHS settings. He is the Director of CEBM and is an NIHR Senior Investigator. He is co-director of the Global Centre for healthcare and Urbanization based at Kellogg College at Oxford, and he is a scientific advisor to Collateral Global. JB is a significant shareholder in the Trip Database search engine (www.tripdatabase.com) and an employee. He has previously received funding from institutions such as WHO, NIHR and Collateral Global.