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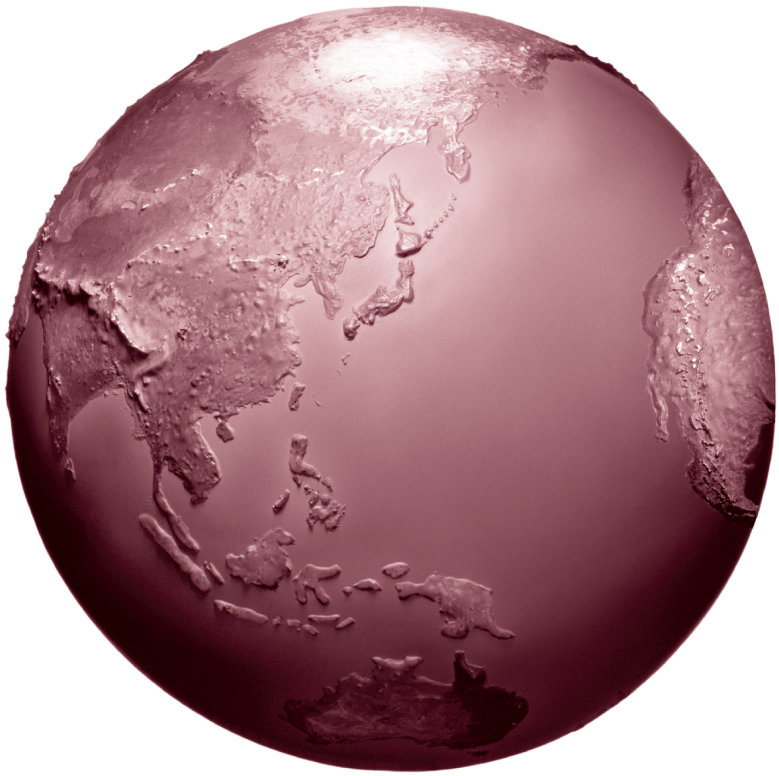

Systematic Review and Meta-analysis of Selected Health Effects of Long-Term Exposure to Traffic-Related Air Pollution

HEI Panel on the Health Effects of Long-Term Exposure to Traffic-Related Air Pollution

EXECUTIVE SUMMARY

Health Effects Institute

ABOUT HEI

The Health Effects Institute is a nonprofit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the effects of air pollution on health. To accomplish its mission, the Institute

- Identifies the highest-priority areas for health effects research
- Competitively funds and oversees research projects
- Provides intensive independent review of HEI-supported studies and related research
- Integrates HEI's research results with those of other institutions into broader evaluations
- Communicates the results of HEI's research and analyses to public and private decision makers.

HEI typically receives balanced funding from the U.S. Environmental Protection Agency and the worldwide motor vehicle industry. Frequently, other public and private organizations in the United States and around the world also support major projects or research programs. HEI has funded more than 340 research projects in North America, Europe, Asia, and Latin America, the results of which have informed decisions regarding carbon monoxide, air toxics, nitrogen oxides, diesel exhaust, ozone, particulate matter, and other pollutants. These results have appeared in more than 260 comprehensive reports published by HEI, as well as in more than 2,500 articles in the peer-reviewed literature.

HEI's independent Board of Directors consists of leaders in science and policy who are committed to fostering the public–private partnership that is central to the organization. The Research Committee solicits input from HEI sponsors and other stakeholders and works with scientific staff to develop a Five-Year Strategic Plan, select research projects for funding, and oversee their conduct. The Review Committee, which has no role in selecting or overseeing studies, works with staff to evaluate and interpret the results of funded studies and related research.

All project results and accompanying comments by the Review Committee (or in this case, the HEI Panel on the Health Effects of Long-Term Exposure to Traffic-Related Air Pollution) are widely disseminated through HEI's website (*www.healtheffects.org*), reports, newsletters and other publications, annual conferences, and presentations to legislative bodies and public agencies.

CONTRIBUTORS

In 2018, the Board of Directors of the Health Effects Institute (HEI) appointed an expert Panel to review the scientific literature on traffic-related air pollution and health. The Panel consisted of scientists from a variety of disciplines and was co-chaired by Francesco Forastiere, Imperial College London, and Frederick Lurmann, Sonoma Technology, Inc., Petaluma, California. During the course of the review, consultants to the Panel were added. In addition, HEI hired a contractor team at the Swiss Tropical and Public Health Institute, Switzerland, to execute certain parts of the review. HEI is indebted to the Panel, the consultants to the Panel, and contract team for their expertise, cooperation, and enthusiasm. A draft of the resulting report was submitted for outside peer review.

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EXECUTIVE SUMMARY

INTRODUCTION

Motor vehicles are a significant source of urban air pollution and are important contributors of anthropogenic carbon dioxide and other greenhouse gases.

Traffic-related air pollution (TRAP*) is a complex mixture of gases and particles resulting from the use of motor vehicles including heavy-duty and light-duty vehicles, buses, passenger cars, and motorcycles. Motor vehicles emit a variety of pollutants including nitrogen oxides (NO_x), elemental carbon (EC), particulate matter ≤2.5 µm in aerodynamic diameter ($PM_{2.5}$), ultrafine particles (UFPs), heavy metals, polycyclic aromatic hydrocarbons, and volatile organic compounds. When emitted through vehicle exhaust, these pollutants are called *tailpipe emissions.* When emitted by other means, such as evaporative emissions of fuel, the resuspension of dust, the wear of brakes and tires, and the abrasion of road surfaces, they are called *nontailpipe emissions*.

Tailpipe emissions from motor vehicles and ambient concentrations of most monitored traffic-related pollutants have decreased steadily over the last several decades in most high-income countries. This trend is a result of air quality regulations and improvements in vehicular emission-control technologies and is likely to continue (Frey 2018). However, decreases in emissions from individual motor vehicles, while substantial, do not fully compensate for the rapid growth and increased vehicular congestion of the motor vehicle fleet due to population growth, urbanization, and economic activity, as well as to the continued presence of older or malfunctioning vehicles on the roads. The adoption of new technologies such as electric vehicles—while promising alleviation of some components of TRAP—has been relatively slow so far due to the slow development and cost of battery technology and infrastructure, electricity decarbonization, nontailpipe emissions mitigation, and fleet turnover (Khreis et al. 2020). However, their sale is growing rapidly as technical and infrastructural barriers are overcome, and government policies and manufacturers' pledge to boost their adoption come to fruition.

Interest in the contribution of nontailpipe emissions to air quality and health is increasing in most high-income countries as vehicle miles traveled increase and regulations continue to be targeted almost exclusively to tailpipe emissions. For the foreseeable future, a substantial number of people globally will continue to be exposed to tailpipe and nontailpipe TRAP, especially in urban settings and residences in proximity to busy roadways.

The rate at which vehicle emissions disperse into ambient air depends on multiple factors that are highly variable, including wind speed, wind direction, atmospheric stability, and terrain and land use. In addition, air pollution from other sources—such as industry, oil, coal and wood burning, and agricultural sources as well as atmospheric transport of pollutants from distant sources—contributes to the overall air quality. The results of these emissions are elevated concentrations of air pollutants through primary emissions and through the formation of secondary pollutants, such as secondary PM and ozone. People are exposed to these air pollutants when outdoors or indoors through the infiltration of outdoor air pollutants. Human exposures are also determined by various dynamic factors such as mobility patterns and distance from the source.

In 2010, HEI published Special Report 17, *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects*. This review, developed by the HEI Panel on the Health Effects of Traffic-Related Air Pollution, summarized and synthesized research on emissions, exposure, and health effects from TRAP and drew conclusions about whether the associations between exposure and health outcomes were causal. The Panel reviewed both toxicological and epidemiological evidence. At that time, the Panel

* A list of abbreviations appears at the end of this Executive Summary.

concluded that the evidence was sufficient to support a causal relationship between exposure to TRAP and exacerbation of asthma in children. The Panel also found suggestive evidence of a causal relationship with the onset of childhood asthma, nonasthma respiratory symptoms in adults, impaired lung function in children and adults, all-cause and cardiovascular mortality, and cardiovascular morbidity. For a number of other health outcomes, there was only limited evidence of associations, and the data were deemed to be either inadequate or insufficient to draw firmer conclusions (HEI 2010).

Since HEI published its review in 2010, many additional studies investigating the health effects of exposure to TRAP have been published, and regulations and vehicular technology have advanced significantly. In addition, there is a better appreciation that, beyond air pollution, traffic can be a source of other exposures with potential relevance to health, most notably noise. These exposures may either confound or modify the health effects of TRAP, which continues to be of public health interest and is of concern to policy makers and motor vehicle manufacturers alike. Therefore, in response to broad interest from its sponsors, HEI decided to conduct a new literature review, as described in HEI's Strategic Plan 2015–2020 (HEI 2015) and reconvened the Panel with new members to conduct the review. The new Panel consisted of 13 experts in epidemiology, exposure assessment, and statistics at institutions in North America and Europe. The resulting Special Report was subjected to detailed peer review. This review is the largest systematic effort to date that evaluates the epidemiological evidence regarding the associations between long-term exposure to TRAP and selected adverse health outcomes.

OBJECTIVE

The overall objective of this Special Report was to systematically evaluate the epidemiological evidence regarding the associations between long-term exposure to TRAP and selected adverse health outcomes. Results were quantitatively combined to evaluate the strength of the evidence, where appropriate. The Panel was charged with drawing conclusions about the confidence in the quality of the body of evidence and with assessing the level of confidence in the presence of an association. The Panel did not assess causality because they did not conduct separate, independent systematic assessments of the mechanistic, toxicological, and human clinical studies relating TRAP to human health. For these reasons, the descriptors of the overall confidence assessment still mention *association* rather than causal association, causal relationship, or effect.

The Special Report describes the methodology and findings from the systematic review of the epidemiological evidence, discusses the strengths and limitations of the evidence base and makes recommendations for future research. In addition to the systematic review of the epidemiological evidence, the Special Report features a section that addresses some important issues related to technologies and emissions from motor vehicles, including a high-level, succinct review on the mechanistic evidence of health effects of exposure to TRAP, and summarizes the health effects of short-term exposure to TRAP. This information, which is not included in this summary, is meant to provide background material and serve as complementary and supporting evidence to the systematic review on the health effects of long-term exposure to TRAP.

GENERAL METHODS

The Panel used a rigorous and systematic approach to search the literature, select studies for inclusion in the review, assess study quality, summarize results, and reach conclusions about the confidence in the body of evidence. The Panel's approach was largely based on standards set by Cochrane, the World Health Organization (WHO), and the National Institute of Environmental Health Sciences. To this end, a review protocol was published in 2019 (HEI 2019) and registered in Prospero, a registry of systematic reviews (*https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=150642*).

Health outcomes were selected by the Panel based on evidence of causality (causal or likely causal), according to the latest determination for general air pollution (broader than TRAP) from available authoritative integrated science assessments and other considerations such as relevance for public health and policy. Selected health outcomes were clinical (rather than preclinical) outcomes and included birth outcomes (e.g., term low birth weight), respiratory outcomes (e.g., asthma onset), cardiometabolic outcomes (e.g., ischemic heart disease [IHD] and diabetes) and all-cause and cause-specific (e.g., circulatory, respiratory) mortality.

A PECOS question (Population, Exposure, Comparator, Outcome and Study) was developed, and then inclusion and exclusion criteria were listed for each PECOS domain in relation to the selected health effects of long-term exposure to TRAP. The focus of the review was on health effects observed in the general population. Cohort, case-control, cross-sectional, and intervention studies using individual-level health outcome data were included.

An extensive search was conducted of literature published between January 1980 and July 2019. Studies were checked for eligibility by two reviewers. Data from all included studies were extracted and evaluated extensively, including key information for meta-analysis. Effect estimates from single-pollutant models were selected as the effect estimates for the meta-analysis. In this review multipollutant models were of less interest as the aim was to assess the TRAP mixture, not individual components. A random-effects meta-analysis was performed when at least three studies were available for a specific exposure–outcome pair. The Panel decided to use the pollutant concentration increments from the ESCAPE

study to reflect a realistic range of exposure contrasts in most studies (Beelen et al. 2014, 2015). Forest plots with meta-analysis estimates were produced, where appropriate. In the Special Report, the forest plots are accompanied by summary tables with important information on the studies. Risk of bias was assessed for all exposure–outcome associations that were included in the meta-analyses using a modified version of the tool developed for the risk of bias assessment in the WHO Air Quality Guidelines review (WHO 2020, 2021). Where possible, additional analyses were performed to assess consistency in subgroups of studies, for example, across geographic region, time period, risk of bias, and confounder adjustment for individual-level behavioral factors (i.e., smoking). An adapted GRADE (Grading of Recommendations Assessment, Development and Evaluation) assessment of the confidence in the quality of the body of evidence was made using the Office of Health Assessment and Translation (OHAT) method as a guide (OHAT 2019). The OHAT confidence rating was heavily geared toward the studies entering a meta-analysis. The Panel thought it was prudent to accompany the OHAT assessment with a broader approach and developed a narrative assessment to evaluate the level of confidence in the presence of an association, considering the meta-analyzed studies as well as other studies not entering the meta-analysis. The findings based on the narrative assessment and the modified OHAT assessment were combined into an overall confidence assessment, with the two approaches considered complementary.

In addition to the systematic review of the selected health outcomes described earlier, literature reviews were developed for neurodevelopmental outcomes in children and dementia-related outcomes and Parkinson disease in adults. Those literature reviews were added because the Panel thought these were important emerging areas that should be represented in the Special Report, even while a larger body of evidence develops. The literature review differs from the systematic review in some important respects: (1) no meta-analyses were conducted, (2) there was no evaluation of the confidence in the quality of the body of evidence, and (3) there was no formal risk of bias assessment on individual studies. Hence, those findings are not included in this Executive Summary.

EXPOSURE FRAMEWORK

Exposure assessment of TRAP is challenging because it is a complex mixture of PM and gaseous pollutants and is characterized by high spatial and temporal variability. Building on the 2010 HEI Traffic Review, which identified the exposure assessment as a significant limitation in the then-current literature, the Panel developed a novel exposure framework to define transparently which studies assessed TRAP and are therefore eligible for inclusion in the current review.

The exposure assessment framework included three strategies to determine whether a study was sufficiently traffic-specific, namely the selection of traffic-related pollutants, the exposure assessment method, and the spatial resolution. None of the selected pollutants is fully specific to traffic and therefore the additional requirements outlined in this summary were needed.

Broadly, emissions from motorized traffic may affect air quality at the local, neighborhood, urban, and regional scale. The Panel judged, however, that epidemiological studies focusing on exposure contrasts at the local and neighborhood scale offered the greatest potential in determining exposure derived from TRAP emissions. The Panel included studies that evaluated exposure to nitrogen dioxide (NO_2), EC (which includes studies using related metrics such as black carbon, black smoke, and PM absorbance), carbon monoxide, UFPs, and other pollutants, and indirect traffic measures (distance and density), as well as $PM_{2.5}$ and PM ≤10 µm in aerodynamic diameter (PM_{10}). For studies that evaluated exposure to $PM_{2.5}$ and PM_{10}, more stringent requirements for inclusion were needed regarding exposure assessment and study setting to indicate that the exposure contrasts were likely due to variation in traffic emissions. For example, the Panel excluded PM studies that were solely based on monitoring data. The Panel also excluded nationwide studies on any pollutant where the primary exposure contrast was due to between-cities variations, rather than within cities.

In addition, the Panel developed a traffic specificity indicator (high or moderate) based on stricter criteria for the three elements of the general framework. For example, all $PM_{2.5}$ and PM_{10} studies were considered as having moderate (as opposed to high) traffic specificity. Furthermore, the spatial scale of the pollution surface needed to be within 1 km for high traffic specificity as opposed to only 5 km for the study to be included in the review. The majority of studies that were included based on the general exposure framework also met the stricter high traffic specificity criteria. The Panel developed two tiers of criteria because it initially thought that only one tier—based on a highly strict set of criteria—would be too restrictive, leading to fewer studies for assessment. The Panel concluded that the finding most studies satisfied the stricter criteria is reassuring and lends confidence to knowing the exposure framework successfully identified studies that are informative of the impact of TRAP on the selected health outcomes.

MAIN FINDINGS OF THE SYSTEMATIC REVIEW

The number of studies on long-term exposure to TRAP and health outcomes included in this review has more than tripled compared with the 2010 HEI Traffic Review (HEI 2010), although a direct comparison is difficult because of the differences in scope, methods, and criteria for study inclusion.

In total, 353 studies were included in the review. Respiratory effects in children (N = 118 studies, 33%) and birth outcomes (N = 86 studies, 24%) were the most common outcomes. Fewer studies investigated cardiometabolic effects (N = 57 studies, 16%), respiratory effects in adults (N = 50 studies, 14%), and mortality (N = 48 studies, 13%). Studies were conducted in populations residing in a wide range of countries, although the majority were done in Europe (N = 163 studies, 46%), and North America (N = 130 studies, 37%). Studies in Asia (predominantly China) emerged more recently (N = 41 studies, 12%). More TRAP studies in low- and middle-income countries are needed.

Most meta-analyses by outcome involved NO_2 as the most commonly studied TRAP exposure indicator, followed by EC and $PM_{2.5}$. Few studies were identified for some pollutants, in particular nontailpipe PM indicators and UFPs, and such studies were identified as a future research need.

The results of the meta-analyses of associations between long-term exposure to the most commonly studied TRAP exposure indicators (NO_2, EC, and $PM_{2.5}$) and selected health outcomes are displayed in the Executive Summary Table. We use the term *relative risk* to describe effect estimates as it is easier to communicate, even if in some of the included studies it would be technically more correct to refer to an odds ratio, or hazard ratio. The following are important considerations while reviewing the results: (1) although the results are presented by pollutant, the individual pollutants are considered indicators of the TRAP mixture; (2) effect estimates cannot be compared directly across traffic-related pollutants because selected increments do not necessarily represent the same contrast in exposure; and (3) studies included in a meta-analysis represent only about half of all studies considered for various reasons, such as when multiple studies conducted in the same population, less than three studies were available for a particular exposure–outcome pair, or definitions of indirect traffic measures varied across studies. Thus, the Panel did not pursue meta-analyses of indirect traffic measures. Despite not being included in the meta-analyses, the remaining studies added important information to the overall confidence assessment.

The Executive Summary Figure and Table provide for each health outcome the overall level of confidence in an association with long-term exposure to TRAP. This overall confidence assessment is a combination of the narrative assessment and the modified OHAT assessment. Detailed descriptors of the overall confidence assessment evidence are listed in the Executive Summary Sidebar.

The Panel found a high or moderate-to-high level of confidence in an association between long-term exposure to TRAP and the adverse health outcomes all-cause, circulatory, ischemic heart disease (IHD), and lung cancer mortality; asthma onset in both children and adults; and acute lower respiratory infections (ALRI) in children. The Panel's confidence in the evidence was considered moderate, low, or very low for the other selected outcomes. The main findings for each broad health outcome category are described in the following sections.

BIRTH OUTCOMES

The summary estimates showed that $PM_{2.5}$ exposure over the entire pregnancy is most clearly associated with measures of fetal growth restriction. The summary relative risk was 1.11 (95% confidence interval [CI]: 1.03 to 1.20) for term low birth weight and 1.09 (1.04 to 1.14) for small for gestational age, and a mean difference in term birth weight of −17.3 (−33.2 to −1.5) grams per 5-μg/m^3. The $PM_{2.5}$ associations were supported by consistent associations with PM_{10} as well. Associations for preterm birth were largely null, although a few studies of traffic-PM and indirect traffic measures (distance and density) supported an association. Associations for the other meta-analyzed traffic-related air pollutants—including NO_2, NO_x, and EC—were mostly null for all four birth outcomes, with the exception of an association of NO_x with term low birth weight. Studies that were not included in the meta-analyses broadly agreed with the summary estimates for the various pollutants.

The majority of TRAP studies and birth outcomes were conducted in North America and Europe. Most used a cohort study design and registry data and therefore lacked potentially important confounder information on lifestyle factors, such as maternal smoking during pregnancy and prepregnancy body mass index. As a result, those studies were rated high risk of bias for potential confounding, which reduced confidence in the quality of the body of evidence, particularly for term birth weight and preterm birth.

The Panel concluded that there was an overall moderate level of confidence in the evidence for an association between TRAP exposure and term low birth weight (categorical outcome) and small for gestational age, and a low level of confidence for term birth weight (continuous outcome) and preterm birth.

RESPIRATORY OUTCOMES

The summary estimates for NO_2 per 10-μg/m^3 were 1.05 (95% CI: 0.99–1.12) for asthma onset in children, 1.10 (1.01–1.21) for asthma onset in adults, and 1.09 (1.03–1.16) for ALRI in children.

For these outcomes, positive associations were also reported for other traffic-related air pollutants, either in meta-analyses or in single large studies. Most of the studies had a cohort design, were conducted in different populations, and were at a low or moderate risk of bias.

The Panel concluded that the overall level of confidence in the evidence for an association between exposure to TRAP and asthma onset in both children and adults and ALRI in children was considered moderate to high. Studies examining

Executive Summary Table. Overall Confidence Assessment and Meta-analytical Summary Estimates of Associations Between Long-Term Exposure to the Most Common Traffic-Related Air Pollutants (NO_2, EC, $PM_{2.5}$) and Health Outcomes (NOTE: the individual pollutants are considered indicators of TRAP)

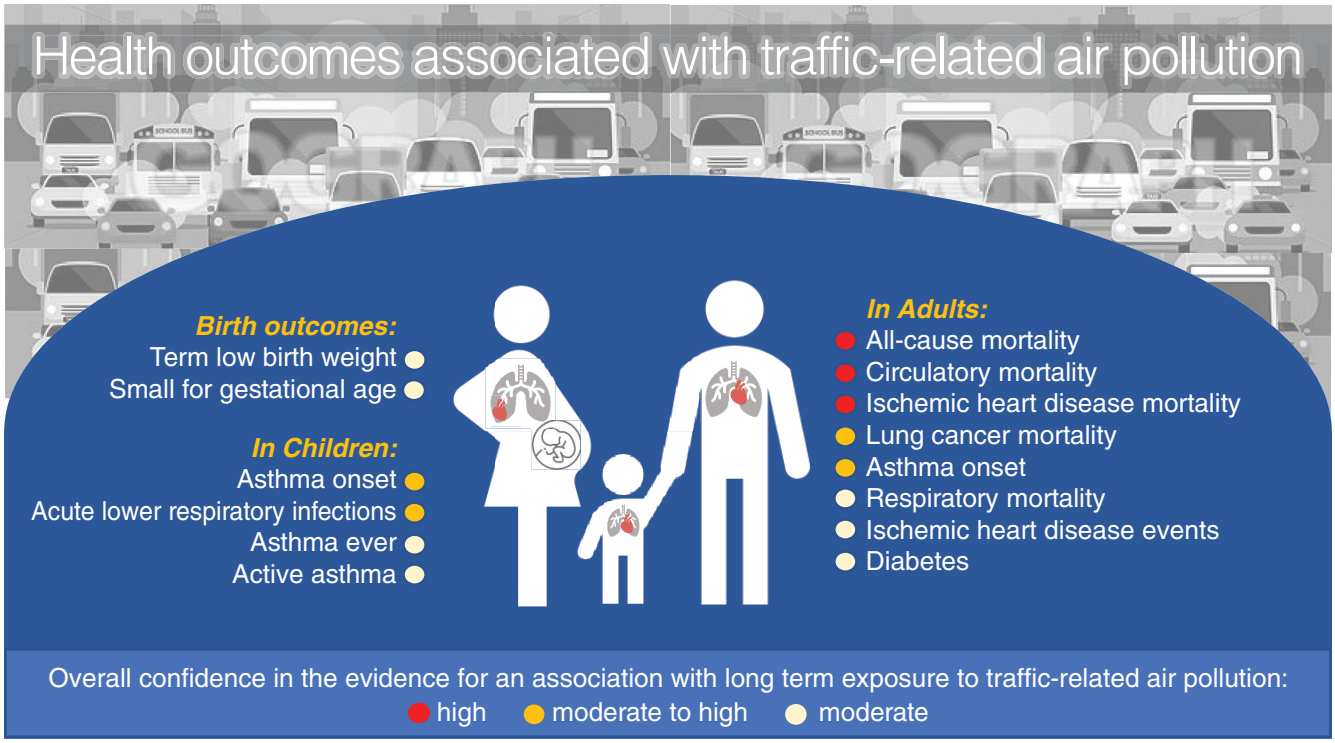
Health Outcome	Overall Confidence Assessment	NO_2 per 10-μg/m³		EC per 1-μg/m³		$PM_{2.5}$ per 5-μg/m³	
		N	Relative Risk (95% CI)	*N*	Relative Risk (95% CI)	*N*	Relative Risk (95% CI)
Birth Outcomes							
Term low birth weight	Moderate	12	1.01 (0.99–1.03)	5	1.01 (0.99–1.04)	7	1.11 (1.03–1.20)
Term birth weight	Low	8	−3.2 (−11.0 to 4.6)[a]	4	−2.6 (−6.1 to 0.9)[a]	6	−17.3 (−33.2 to −1.5)[a]
Small for gestational age	Moderate	11	1.00 (0.98–1.02)	3	1.02 (0.92–1.14)	4	1.09 (1.04–1.14)
Preterm birth	Low	14	1.00 (0.96–1.04)	5	1.02 (0.97–1.07)	4	0.99 (0.90–1.09)
Respiratory Outcomes—Children							
Asthma onset[b]	Moderate to high	12	1.05 (0.99–1.12)	5	1.11 (0.94–1.31)	5	1.33 (0.90–1.98)
Asthma ever[c]	Moderate	21	1.09 (1.01–1.18)	3	1.30 (0.56–3.04)	3	1.29 (0.58–2.87)
Active asthma[c]	Moderate	12	1.12 (1.02–1.23)	3	1.25 (0.98–1.59)	<3	NA
ALRI[b]	Moderate to high	11	1.09 (1.03–1.16)	4	1.30 (0.78–2.18)	<3	NA
Respiratory Outcomes—Adults							
Asthma onset[b]	Moderate to high	7	1.10 (1.01–1.21)	<3	NA	<3	NA
ALRI[b]	Very low to low	3	1.07 (0.71–1.61)	<3	NA	<3	NA
COPD[b]	Low	7	1.03 (0.94–1.13)	<3	NA	4	0.91 (0.62–1.36)
Cardiometabolic Outcomes							
IHD events[b]	Moderate	5	0.99 (0.94–1.05)	5	1.01 (0.99–1.03)	4	1.09 (0.86–1.39)
Coronary events[b]	Low	7	1.03 (0.95–1.11)	<3	NA	<3	NA
Stroke events[b]	Low to moderate	7	0.98 (0.92–1.05)	6	1.03 (0.98–1.09)	4	1.08 (0.89–1.32)
Diabetes[b]	Moderate	7	1.04 (0.96–1.13)	3	1.16 (0.57–2.36)	4	1.05 (0.96–1.15)
Diabetes[c]		7	1.09 (1.02–1.17)	<3	NA	3	1.08 (0.70–1.67)
Mortality							
All-cause	High	11	1.04 (1.01–1.06)	11	1.02 (1.00–1.04)	12	1.03 (1.01–1.05)
Circulatory	High	10	1.04 (1.00–1.09)	9	1.02 (1.00–1.04)	11	1.04 (1.01–1.08)
Respiratory	Moderate	8	1.05 (1.00–1.09)	8	1.01 (0.98–1.05)	7	1.03 (0.97–1.10)
Lung cancer	Moderate to high	5	1.04 (1.01–1.07)	3	1.02 (0.88–1.19)	6	1.06 (0.99–1.13)
IHD	High	6	1.05 (1.03–1.08)	6	1.05 (0.99–1.11)	7	1.07 (1.04–1.10)
Stroke	Low to moderate	6	1.01 (0.98–1.04)	<3	NA	3	1.04 (1.01–1.07)
COPD	Low	3	1.03 (1.00–1.05)	<3	NA	<3	NA

95% CI = 95% confidence interval; ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; IHD = ischemic heart disease; NA = not applicable.

[a] Mean difference in grams.

[b] Incidence.

[c] Prevalence.



Executive Summary Figure. Overall confidence in the evidence for an association between long-term exposure to TRAP and selected health outcomes. Health outcomes for which the overall confidence in the evidence was low to moderate, low, or very low are not in the figure.

exposure to NO_2 have made the greatest contribution to this evaluation. The overall level of confidence in the evidence for an association between TRAP and asthma ever and active asthma in children was moderate. Asthma ever refers to lifetime asthma prevalence and active asthma refers to prevalence of asthma in the last 12 months.

For most of the other respiratory outcomes investigated—including incidence of chronic obstructive pulmonary disease (COPD) and ALRI in adults, and wheeze outcomes as well as exacerbation of asthma and COPD in diseased adults—the confidence was very low or low for an association with TRAP, hampered in part by the small number of qualifying studies.

CARDIOMETABOLIC OUTCOMES

The summary estimates were mostly positive and were consistent with an association of PM_{10} with IHD: 1.14 (95% CI: 0.99–1.31) per 10-μg/m^3, with evidence suggesting a monotonic exposure–response function. Evidence was suggestive for EC and $PM_{2.5}$ but was less consistent overall. Associations were reported with NO_2 and diabetes prevalence with a summary estimate of 1.09 (1.02–1.17) per 10-μg/m^3, supported by consistent positive but imprecise estimates for the other pollutants. The summary estimates of EC, PM_{10}, and $PM_{2.5}$ with stroke incidence were slightly less precise, but the evidence was strengthened by several high-quality studies with a monotonic exposure–response function. Studies that were not included in meta-analyses provided additional support for an association between TRAP and IHD, diabetes, and stroke. In contrast, for coronary events the number of studies was smaller and insufficient for meta-analyses, except for NO_2, which yielded a positive but imprecise association. Because cardiometabolic outcomes are likely influenced by traffic noise, some studies investigated possible confounding or effect modification by noise with mostly similar results after adjustment for co-exposure to noise.

The Panel had overall moderate confidence in the evidence for associations between long-term exposure to TRAP and IHD and to TRAP and diabetes; low-to-moderate confidence in the evidence for an association of TRAP with stroke; and low confidence in the evidence for an association of TRAP with coronary events.

MORTALITY

The summary estimates showed that NO_2, EC, and $PM_{2.5}$ were associated with all-cause, circulatory, IHD, respiratory, and lung cancer mortality, ranging from 1.01 to 1.07. Associations of these pollutants with stroke and COPD mortality were less certain because fewer studies were available for consideration. The studies on pollutants not included in the meta-analyses and the studies with indirect traffic measures supported those associations. All studies on mortality were

EXECUTIVE SUMMARY SIDEBAR

OVERALL CONFIDENCE ASSESSMENT: DESCRIPTORS OF THE LEVEL OF CONFIDENCE IN THE EVIDENCE FOR AN ASSOCIATION[a]

High	Evidence is sufficient to conclude that the strength of the evidence for an association is high; that is, the exposure has been shown to be associated with health effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. The determination is based on multiple high-quality studies conducted in different populations and geographical areas with consistent results for multiple exposure indicators.
	High confidence in the association between exposure and the outcome.
Moderate	Evidence is sufficient to conclude that an association is likely to exist; that is, the exposure has been shown to be associated with health effects in studies where results are not explained by chance, confounding, and other biases, but uncertainties remain in the evidence overall. The determination is based on some high-quality studies in different populations and geographical areas, but the results are not entirely consistent across areas and for multiple exposure indicators.
	Moderate confidence in the association between exposure and the outcome.
Low	Evidence is suggestive but limited, and chance, confounding, and other biases cannot be ruled out. Generally, the body of evidence is relatively small with few high-quality studies available; however, at least one high-quality epidemiological study shows an association with a given health outcome and/or when the body of evidence is relatively large, but the evidence from studies of varying quality and across multiple exposure indicators is generally supportive although not entirely consistent.
	Low confidence in the association between exposure and the outcome.
Very low	Evidence is inadequate to determine if an association exists with the relevant exposures. The available studies are of insufficient quantity, quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an association.
	Very low confidence in the association between exposure and the outcome.

[a] The overall confidence assessment of the association of each health outcome with long-term exposure to TRAP is a combination of the narrative assessment and the modified OHAT assessment. The descriptors are modified from the U.S. Environmental Protection Agency (2015) and the OHAT (2019).

cohort studies, with outcome during follow-up determined by linkage to mortality registries. Most studies were conducted in North America and Europe; some were set in Asia. The majority of studies accounted for a large number of individual and area-level covariates—including smoking, body mass index, and individual and area-level socioeconomic status—and were judged at a low or moderate risk for bias.

The overall confidence in the evidence for an association between TRAP exposure and mortality was high for all-cause, circulatory, and IHD mortality. The Panel's overall confidence was moderate to high for lung cancer, moderate for respiratory, low to moderate for stroke, and low for COPD mortality.

OVERALL CONCLUSIONS

The findings from the systematic review, meta-analyses, and evaluation of the quality of the studies and potential biases have provided an overall high or moderate-to-high level of confidence in an association between long-term exposure to TRAP and the adverse health outcomes all-cause, circulatory, IHD, and lung cancer mortality; asthma onset in both children and adults; and ALRI in children. The Panel's confidence in the evidence was considered moderate, low, or very low for the other selected outcomes.

Tailpipe emissions from motor vehicles and ambient concentrations of most monitored traffic-related pollutants have decreased steadily over the last several decades in most high-income countries. The Panel's main findings were derived from studies conducted when exposure levels were generally higher than present-day levels in high-income countries and comparable to or lower than present-day levels in low-income countries.

In light of the large number of people exposed to TRAP—both in and beyond the near-road environment—the Panel concluded that the overall high or moderate-to-high level of confidence in the evidence for an association between long-term exposure to TRAP and several adverse health outcomes

indicates that exposures to TRAP remain an important public health concern and deserve greater attention from the public and from policymakers.

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ABBREVIATIONS

ALRI	acute lower respiratory infection
CI	confidence interval
COPD	chronic obstructive pulmonary disease
EC	elemental carbon
ESCAPE	European Study of Cohorts for Air Pollution Effects
IHD	ischemic heart disease
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
OHAT	Office of Health Assessment and Translation
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
PM_{10}	particulate matter ≤10 μm in aerodynamic diameter
TRAP	traffic-related air pollution
UFPs	ultrafine particles
WHO	World Health Organization

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