Symposium annuel du
Centre cérébrovasculaire
CHUV

Impact de l'environnement sur l'AVC

Professeur Yannick Béjot

Service Hospitalo-Universitaire de Neurologie, CHU Dijon Bourgogne

Université Bourgogne Europe

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CHU Dijon Bourgogne — Université Bourgogne Europe — Dijon Stroke Registry — DiSCo Dijon Stroke Cohort — PEC2 Équipe d'accueil - EA 7460 — UFR Sciences de Santé Dijon — StrokeLink F-CRIN Network — Inserm — Santé publique France — SFNV Société Française Neuro-Vasculaire

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Vice-Président SFNV

World Stroke Organization group on climate and stroke

Associate Editor: Frontiers in Neurology

Editorial Board: Neuroepidemiology

Epidemiological challenge of stroke

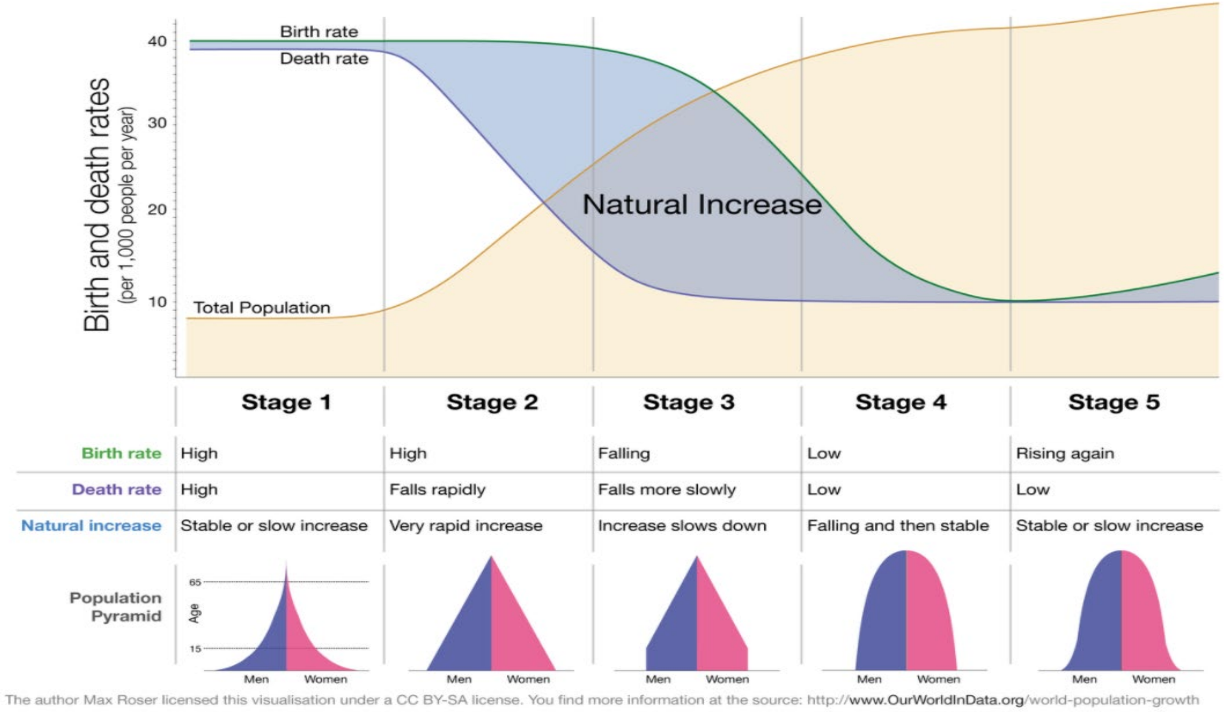
Leading causes of global DALYs Worldwide

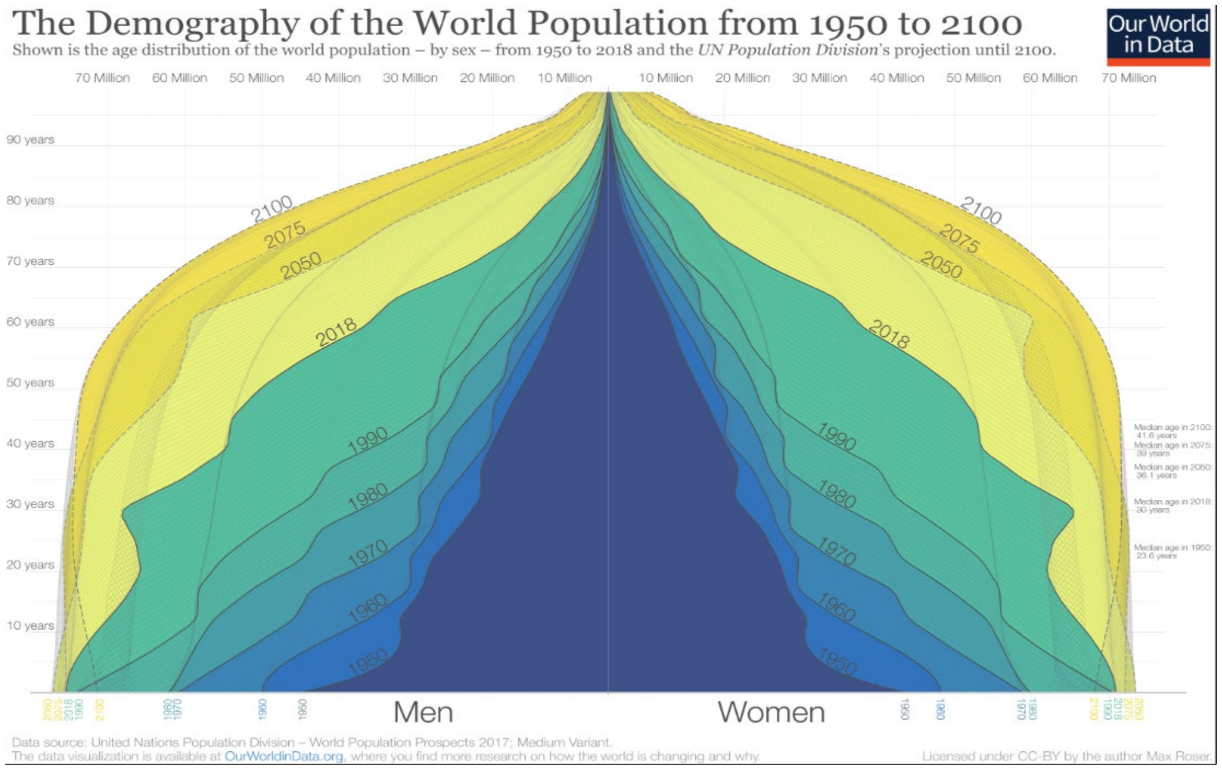
GDB, Lancet. 2024:S0140-6736(24)00757-8.

Leading causes, 2010	DALY count (millions)	Leading causes, 2020	DALY count (millions)	Leading causes, 2021	DALY count (millions)
1 Neonatal disorders	236·3 (218·9–256·4)	1 Neonatal disorders	192·6 (168·2–220·6)	1 COVID-19	212·0 (198·0–234·5)
2 Ischaemic heart disease	159·9 (153·8–164·9)	2 Ischaemic heart disease	185·1 (175·2–194·5)	2 Ischaemic heart disease	188·3 (176·7–198·3)
3 Stroke	144·3 (137·3–150·3)	3 Stroke	158·2 (146·4–168·8)	3 Neonatal disorders	186·3 (162·3–214·9)
4 Lower respiratory infections	127·3 (115·4–140·0)	4 COVID-19	123·4 (116·3–132·5)	4 Stroke	160·4 (148·0–171·7)
5 Diarrhoeal diseases	104·1 (86·7–123·2)	5 Lower respiratory infections	88·2 (78·1–99·4)	5 Lower respiratory infections	82·5 (72·9–93·2)
6 Road injuries	74·3 (70·9–78·4)	6 COPD	78·4 (72·1–84·3)	6 COPD	79·8 (74·0–86·0)
7 HIV/AIDS	67·8 (60·4–78·3)	7 Diabetes	76·5 (64·9–92·2)	7 Diabetes	78·9 (66·8–94·5)
8 Congenital birth defects	67·5 (55·9–82·5)	8 Low back pain	69·3 (49·5–92·8)	8 Other COVID-19 outcomes	77·4 (59·7–101·9)
9 COPD	67·0 (62·9–70·5)	9 Road injuries	65·1 (61·0–69·8)	9 Low back pain	70·2 (50·2–94·1)
10 Malaria	66·4 (37·7–105·9)	10 Diarrhoeal diseases	61·6 (49·6–75·5)	10 Road injuries	65·1 (60·7–69·8)

Epidemiological challenge of stroke

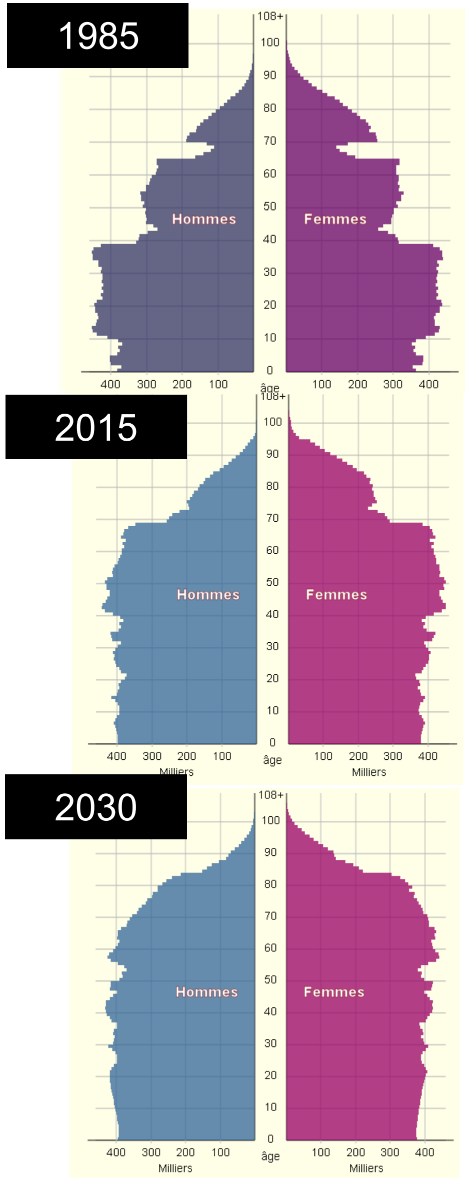
Ongoing demographic transition





Epidemiological challenge of stroke

Age distribution in France

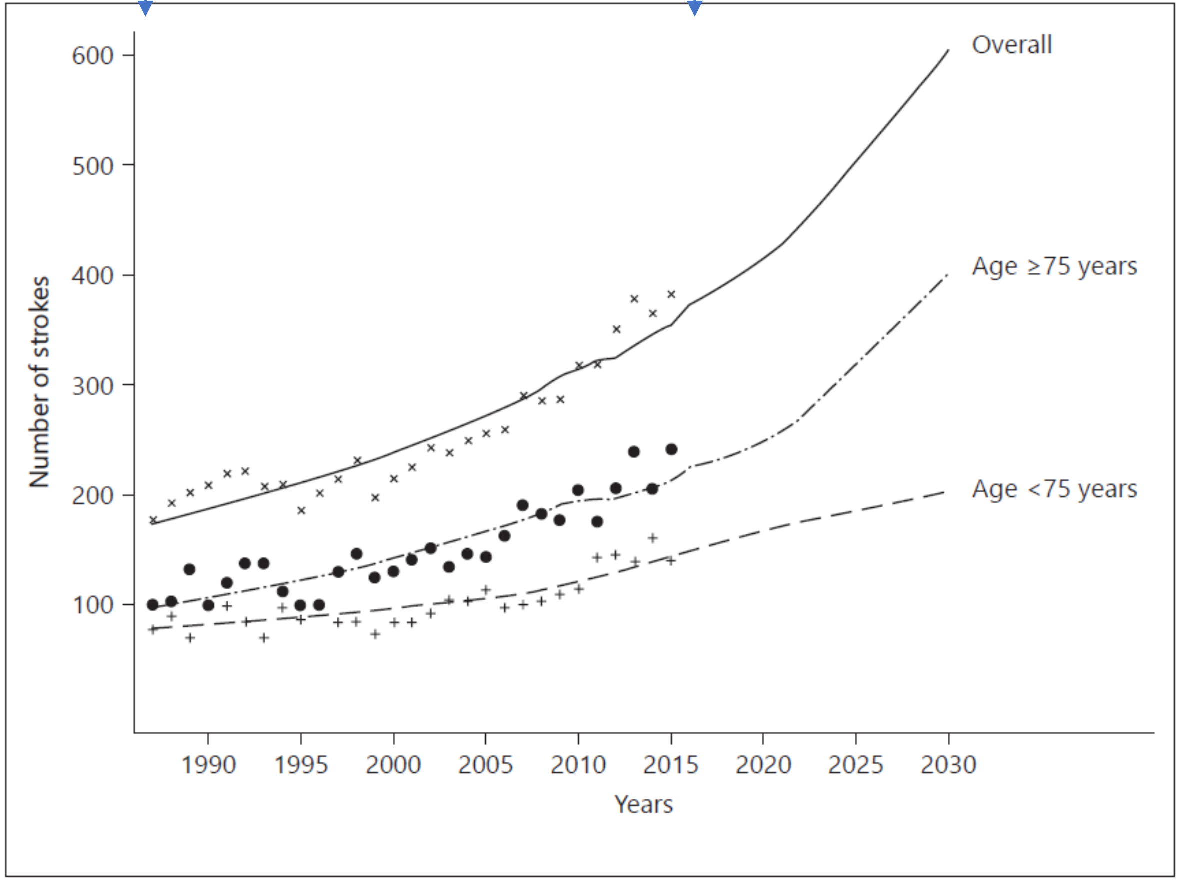


Dijon Stroke Registry

Béjot Y, Neuroepidemiology 2019;52:78–85

145,000 habitants
9.6% > 75 ans

156,000 habitants
12.4% > 75 ans



An expected **50% increase** in the total number of stroke between 2010 and 2030

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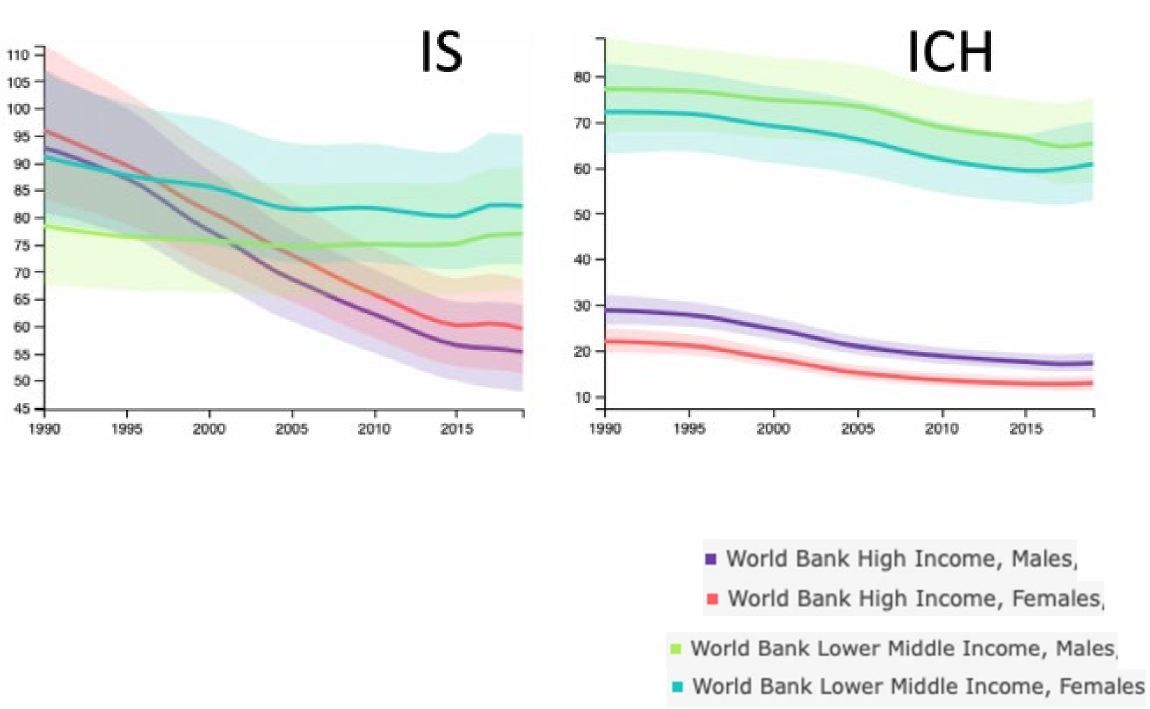
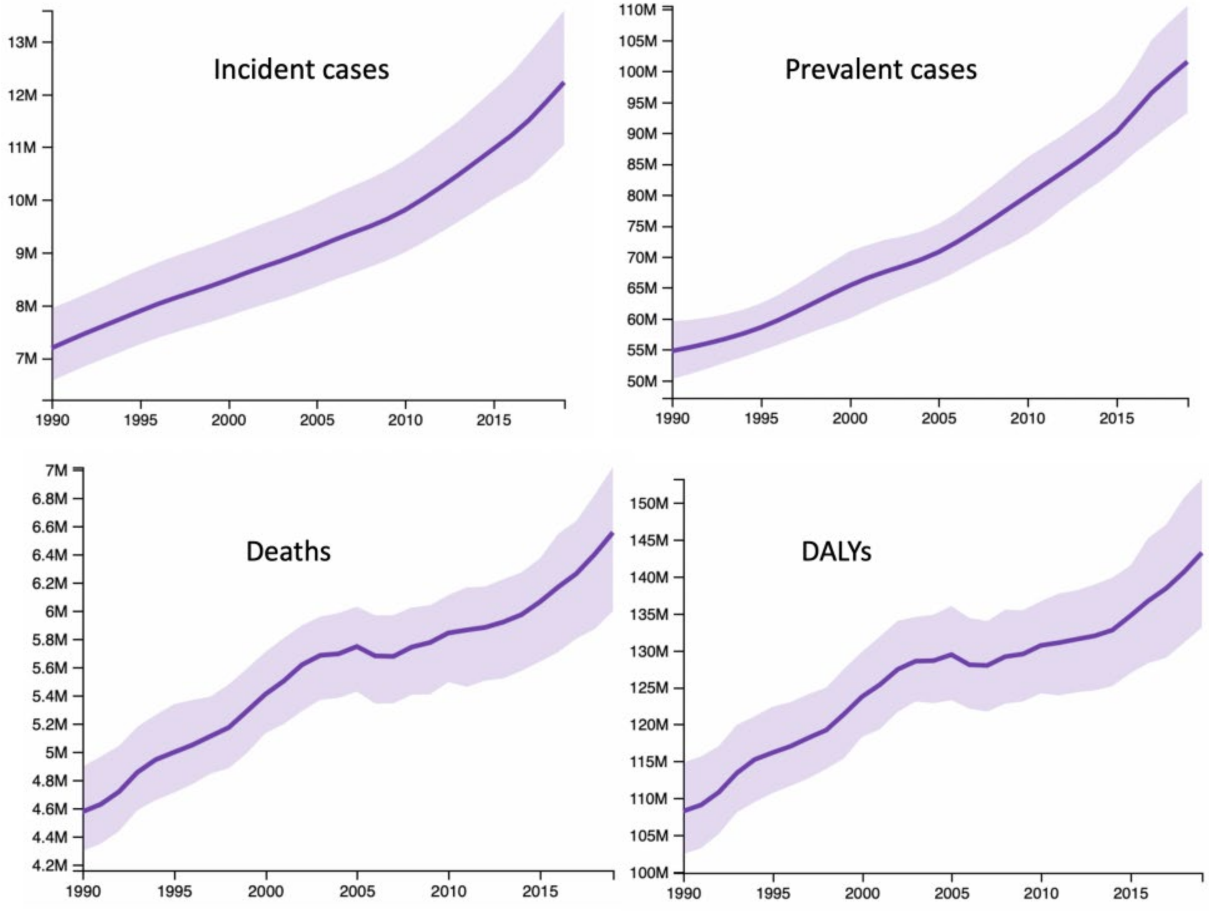
Epidemiological challenge of stroke

Age-standardized incidence rates



Absolute numbers



GBD 2019, Lancet Neurol 2021; 20: 795–820

Epidemiological challenge of stroke

By 2050:

- 200 million stroke survivors
- 30 million new strokes each year
- 12 million deaths from stroke each year
- … and 150 million people with dementia and 5 million deaths from dementia each year

Global Burden of Disease

Environmental factors of stroke - overview

Climate change

Extreme temperature

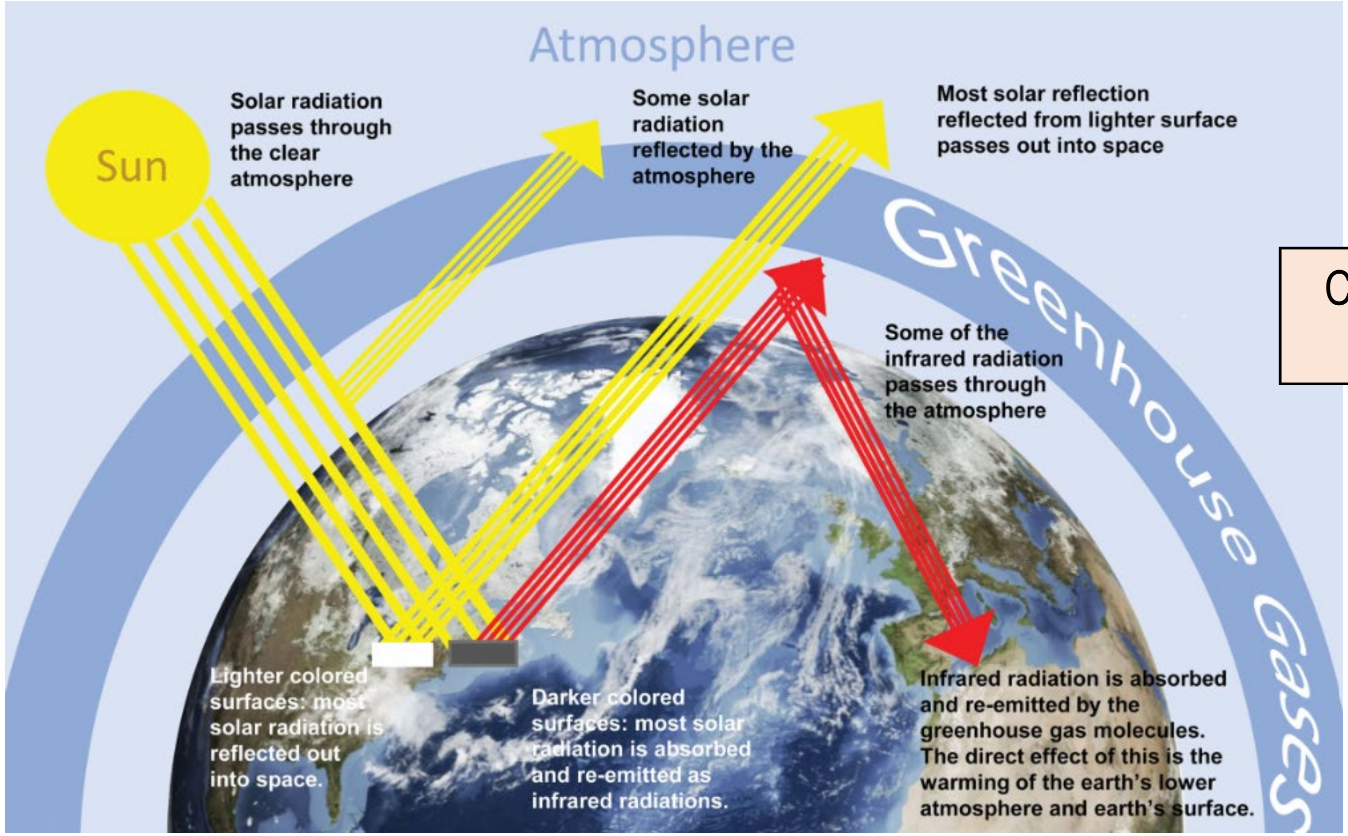
Air Pollution

Urbanization

Soil and water pollution

Relationship between climate change, pollution and temperature

Increase in greenhouse gas emissions is the main driver of climate change



Ranta A, Stroke. 2024;55:1118-1128

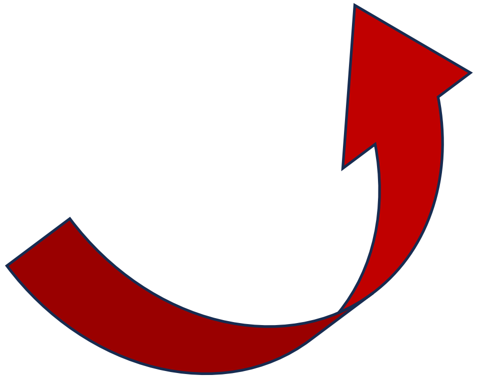
Anthropogenic air pollution

CO2 - NOx - SO2 - O3 - PM2.5 - PM10

Natural pollution

Wildfires
Dust storms
…

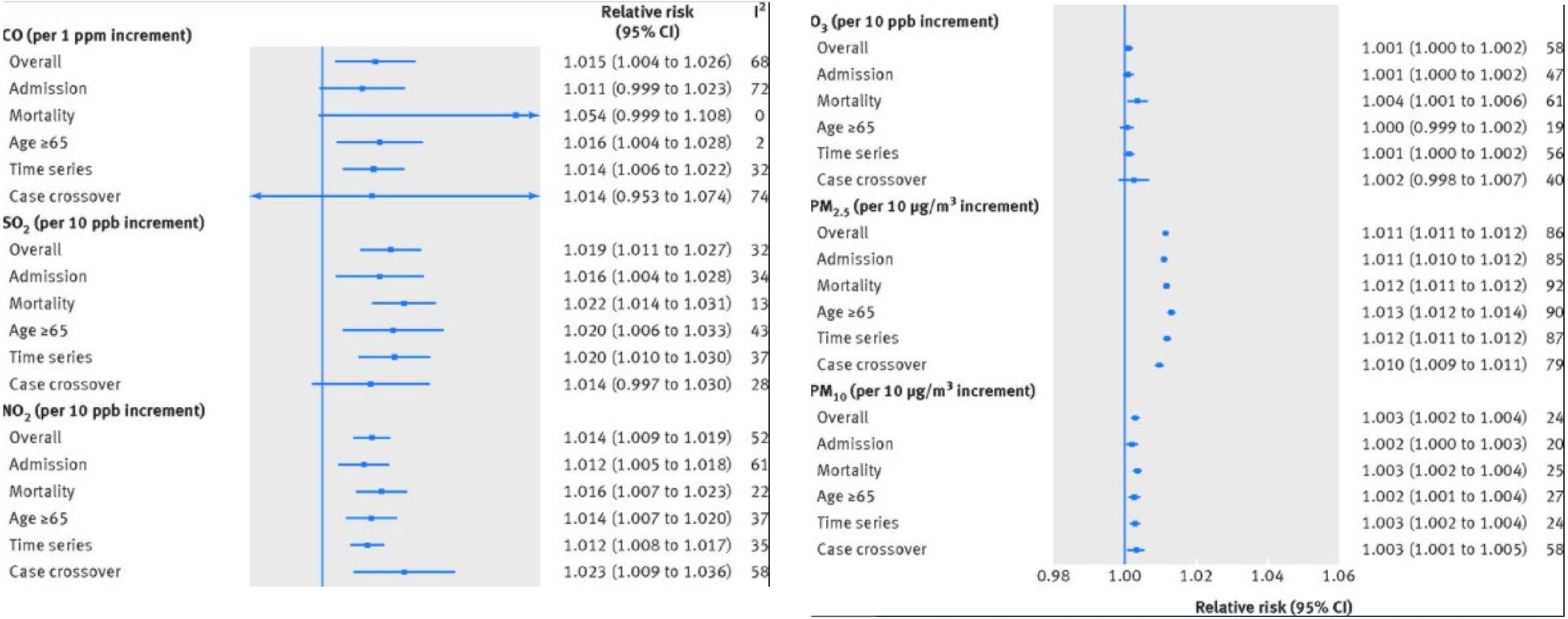
+++



Ambient air pollution and stroke

Short-term exposure

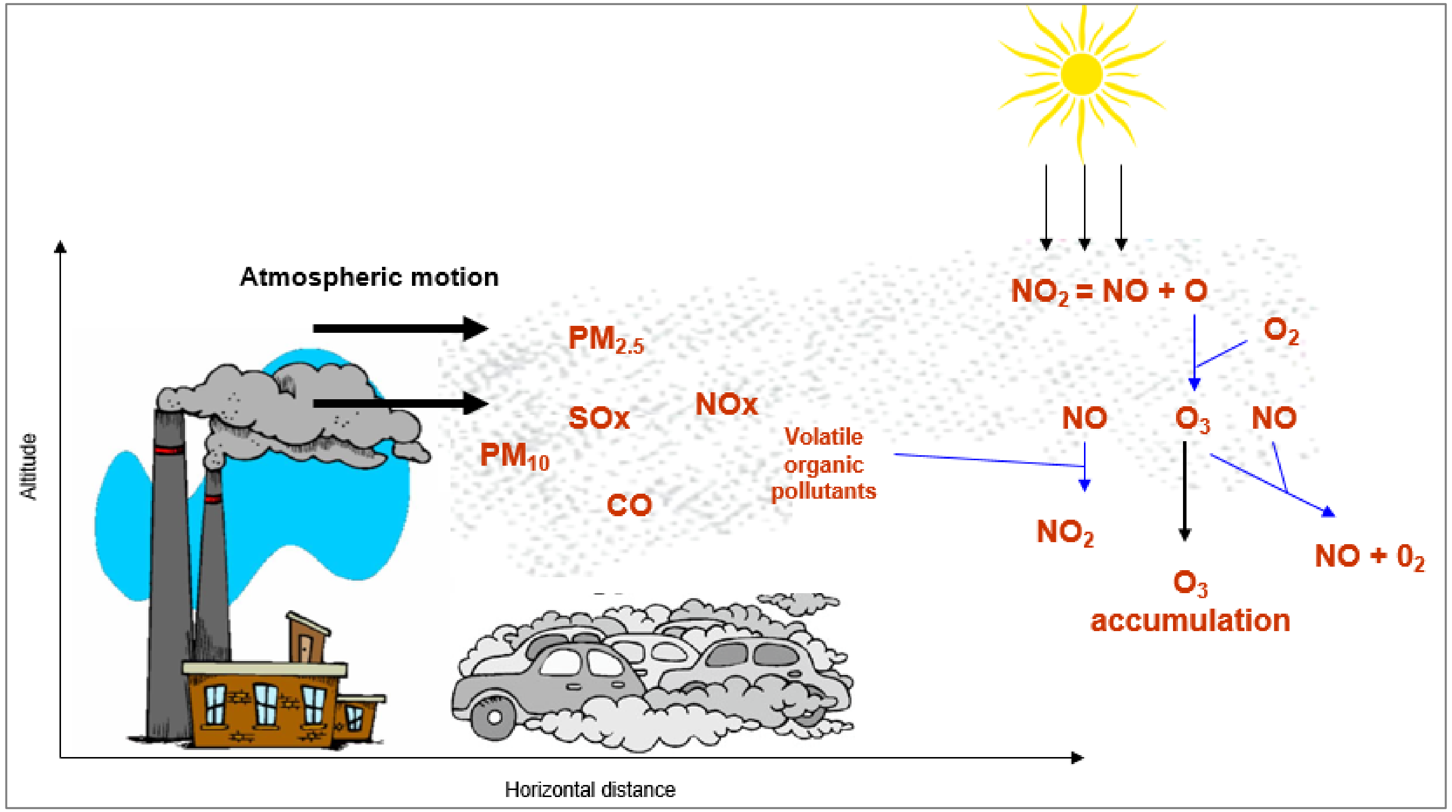
Shah ASV, BMJ. 2015;350:h1295



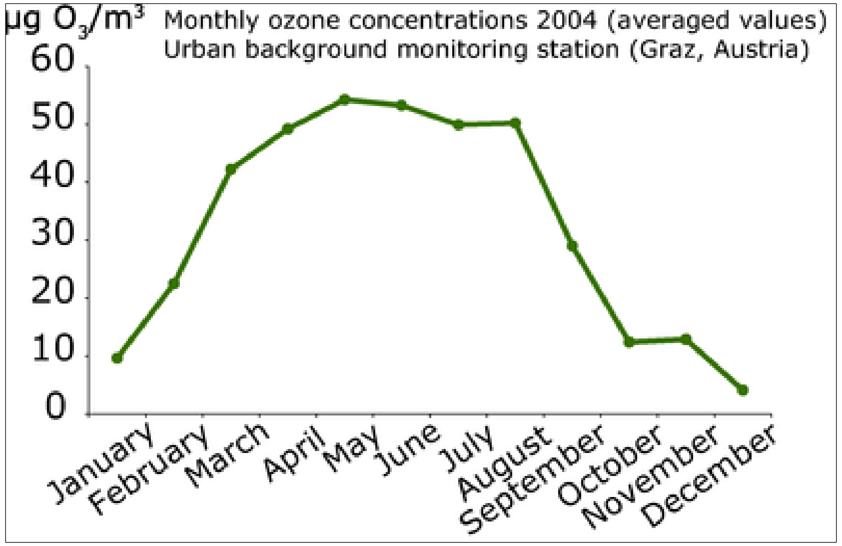
Ambient air pollution and stroke

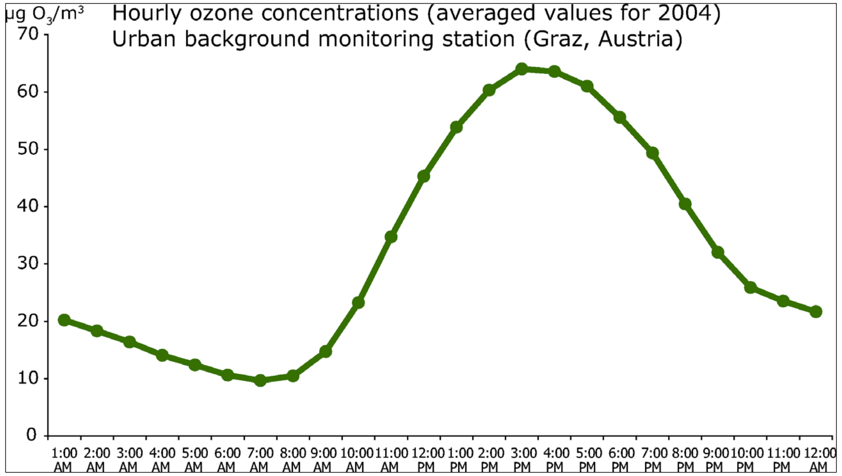
Short-term exposure

Ozone pollution



Béjot Y, Cerebrovasc Dis 2011;32:589–613





Source: European Environment Agency

Short-term exposure

Ozone pollution

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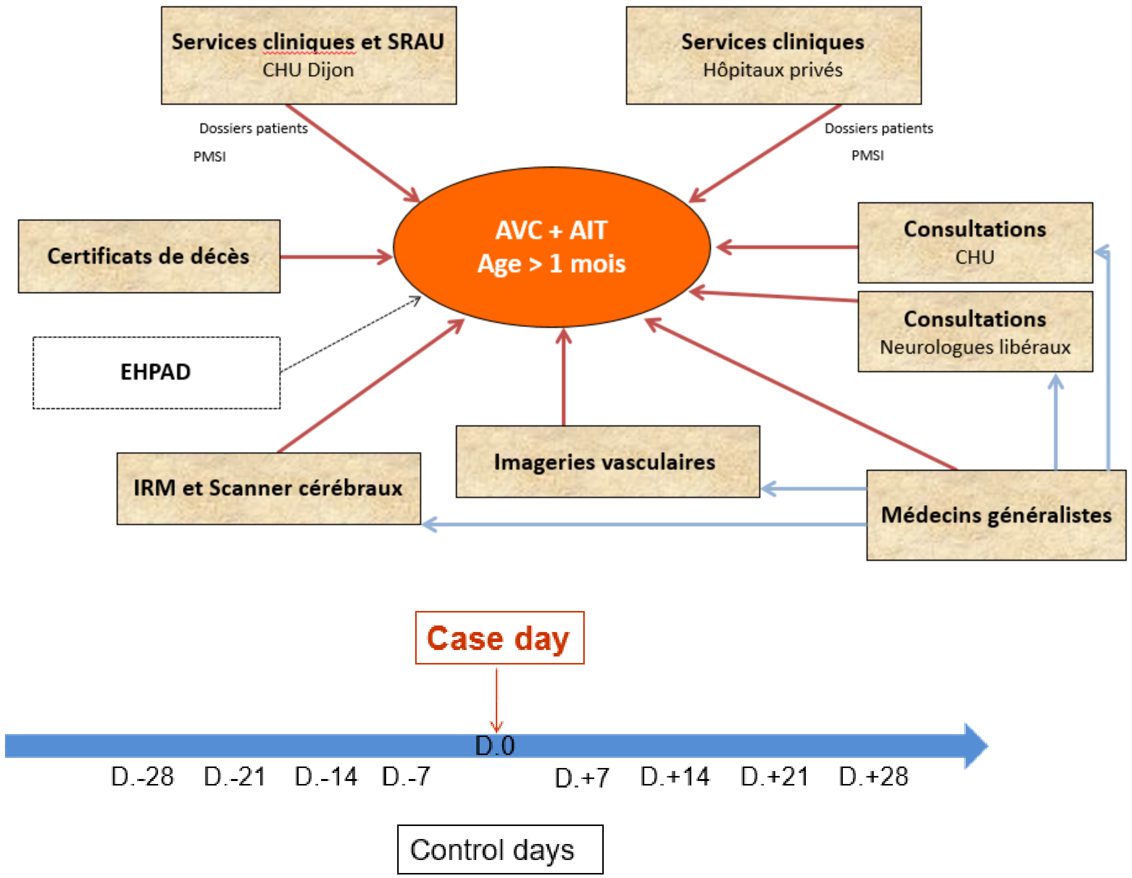
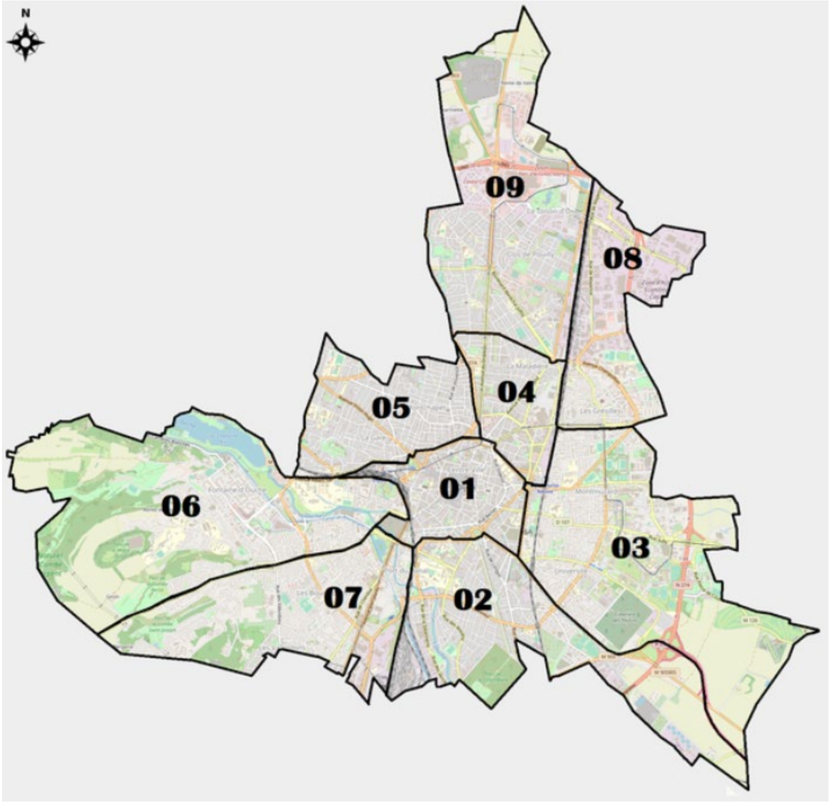




Béjot Y, Cerebrovasc Dis 2011;32:589–613

Ambient air pollution and stroke

Short-term exposure

Ozone pollution

Henrotin JB, Occup Environ Med 2007;64:439-45

Association between air pollutants and the occurrence of stroke

	Ischaemic stroke (women and men), n = 1487		Haemorrhagic stroke (women and men), n = 220		Ischaemic stroke (men), n = 689		Ischaemic stroke (women), n = 798	
Pollutants	ORa (95% CI)	p Value	ORa (95% CI)	p Value	ORa (95% CI)	p Value	ORa (95% CI)	p Value
SO_2								
D0	0.978 (0.868 to 1.103)	0.72	1.099 (0.815 to 1.483)	0.53	0.900 (0.748 to 1.081)	0.26	1.044 (0.892 to 1.222)	0.58
D-1	0.978 (0.863 to 1.108)	0.73	1.014 (0.747 to 1.376)	0.92	0.981 (0.813 to 1.183)	0.84	0.975 (0.824 to 1.153)	0.77
D-2	1.015 (0.902 to 1.143)	0.79	0.961 (0.712 to 1.297)	0.79	1.109 (0.935 to 1.315)	0.23	0.939 (0.797 to 1.106)	0.45
D-3	1.003 (0.892 to 1.127)	0.95	0.954 (0.729 to 1.248)	0.73	1.033 (0.862 to 1.237)	0.72	0.981 (0.841 to 1.144)	0.80
NO_x								
D0	1.008 (0.956 to 1.062)	0.76	0.974 (0.845 to 1.122)	0.71	1.002 ()0.925 to 1.084	0.95	1.013 (0.943 to 1.087)	0.71
D-1	0.966 (0.915 to 1.019)	0.21	1.015 (0.887 to 1.162)	0.82	0.939 (0.866 to 1.018)	0.12	0.987 (0.919 to 1.061)	0.73
D-2	0.996 (0.945 to 1.050)	0.90	0.975 (0.851 to 1.117)	0.72	1.013 (0.938 to 1.094)	0.73	0.982 (0.913 to 1.055)	0.62
D-3	1.027 (0.975 to 1.082)	0.30	0.936 (0.816 to 1.074)	0.34	1.016 (0.941 to 1.097)	0.67	1.037 (0.966 to 1.114)	0.30
O_3								
D0	1.046 (0.998 to 1.098)	0.059	1.012 (0.902 to 1.158)	0.73	1.058 (0.987 to 1.134)	0.10	1.036 (0.969 to 1.106)	0.29
D-1	1.075 (1.022 to 1.131)	0.005	0.974 (0.978 to 1.122)	0.75	1.133 (1.052 to 1.220)	0.001	1.027 (0.958 to 1.101)	0.44
D-2	1.012 (0.965 to 1.062)	0.60	0.958 (0.842 to 1.090)	0.51	1.020 (0.951 to 1.092)	0.57	1.006 (0.941 to 1.075)	0.85
D-3	0.987 (0.943 to 1.043)	0.60	0.970 (0.856 to 1.098)	0.63	1.000 (0.935 to 1.068)	1.00	0.976 (0.915 to 1.040)	0.46
CO								
D0	0.999 (0.997 to 1.001)	0.43	1.000 (0.996 to 1.004)	0.70	0.998 (0.995 to 1.000)	0.15	1.000 (0.998 to 1.002)	0.84
D-1	0.998 (0.997 to 1.000)	0.17	1.001 (0.997 to 1.005)	0.54	0.998 (0.995 to 1.000)	0.19	0.999 (0.997 to 1.001)	0.70
D-2	0.999 (0.998 to 1.001)	0.82	0.999 (0.995 to 1.004)	0.88	1.000 (0.997 to 1.002)	0.96	0.999 (0.997 to 1.001)	0.70
D-3	1.000 (0.998 to 1.001)	0.93	0.998 (0.994 to 1.002)	0.46	1.000 (0.998 to 1.003)	0.62	0.999 (0.997 to 1.002)	0.72
PM_{10}§								
D0	1.009 (0.930 to 1.094)	0.82	0.901 (0.730 to 1.111)	0.33	0.973 (0.862 to 1.098)	0.66	1.040 (0.933 to 1.160)	0.47
D-1	1.011 (0.998 to 1.094)	0.77	1.014 (0.828 to 1.241)	0.85	0.969 (0.860 to 1.091)	0.60	1.047 (0.942 to 1.163)	0.39
D-2	0.960 (0.889 to 1.036)	0.30	1.100 (0.903 to 1.339)	0.34	0.981 (0.877 to 1.098)	0.74	0.941 (0.847 to 1.045)	0.26
D-3	0.990 (0.919 to 1.066)	0.79	0.991 (0.881 to 1.212)	0.93	0.985 (0.881 to 1.102)	0.80	0.993 (0.899 to 1.096)	0.89

DIJON STROKE REGISTRY

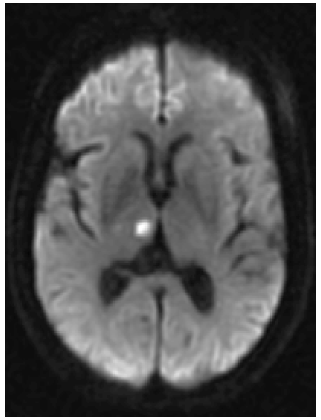
Short-term exposure

Henrotin JB, Occup Environ Med 2007;64:439-45

Ozone pollution

Odds ratio between ischemic strokes subtypes and pollutant concentration from 1-day lag, **in men**

Pollutant	Ischaemic stroke: large arteries (n=262)† ORa (95% CI)	p Value	Ischaemic stroke: lacunar (n=193)‡ ORa (95% CI)	p Value	Ischaemic stroke: cardioembolic (n=208)§ ORa (95% CI)	p Value	Ischaemic stroke: transient ischaemic attacks (n=172)¶ ORa (95% CI)	p Value
SO_2	1.088 (0.785 to 1.508)	0.61	0.831 (0.605 to 1.412)	0.25	0.974 (0.707 to 1.344)	0.87	0.966 (0.659 to 1.416	0.86
NO_x	0.988 (0.863 to 1.130)	0.20	0.896 (0.771 to 1.042)	0.15	1.028 (0.888 to 1.190)	0.70	0.860 (0.742 to 1.022)	0.09
O_3	1.140 (1.013 to 1.288)	0.03	1.077 (0.931 to 1.245)	0.31	1.113 (0.970 to 1.278)	0.12	1.206 (1.038 to 1.401)	0.01
CO	0.998 (0.994 to 1.003)	0.64	0.997 (0.992 to 1.001)	0.24	0.999 (0.995 to 1.004)	0.91	0.999 (0.995 to 1.004)	0.91
PM_{10}*	0.938 (0.769 to 1.144)	0.52	0.881 (0.698 to 1.111)	0.28	1.101 (0.895 to 1.354)	0.36	1.095 (0.833 to 1.432)	0.50



DIJON STROKE REGISTRY

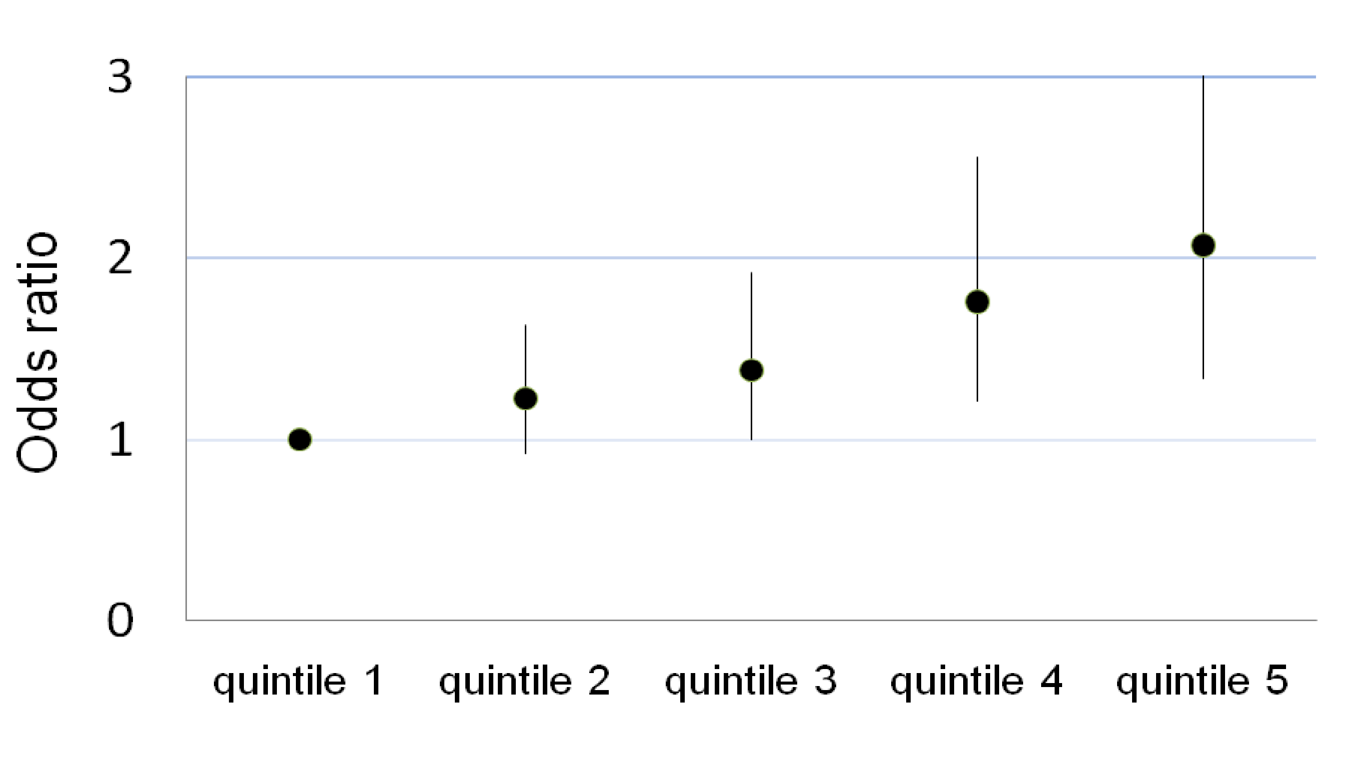
Ambient air pollution and stroke

Short-term exposure

Ozone pollution

Henrotin JB, Occup Environ Med 2007;64:439-45

Odds ratio between ischemic strokes subtypes and pollutant concentration from 1-day lag, **in men**



Quintile 1: < 9 µg/m^3

Quintile 2: 9-20 µg/m^3

Quintile 3: 21-32 µg/m^3

Quintile 4: 33-48 µg/m^3

Quintile 5: > 48 µg/m^3

DIJON STROKE REGISTRY

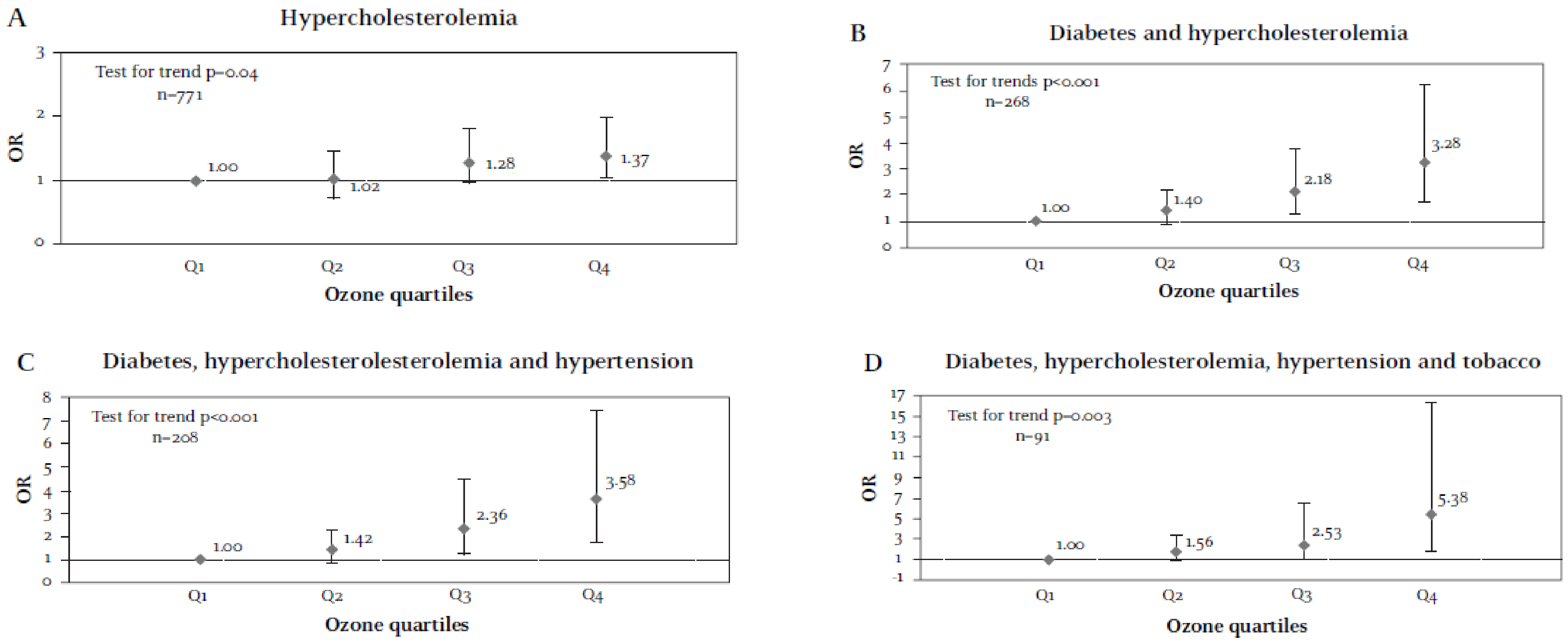
Ambient air pollution and stroke

Short-term exposure

Henrotin JB, Heart 2010;96:1190-1996

Ozone pollution

Dose-response relationship (with 1-day lag) between O3 quartiles and ischemic events



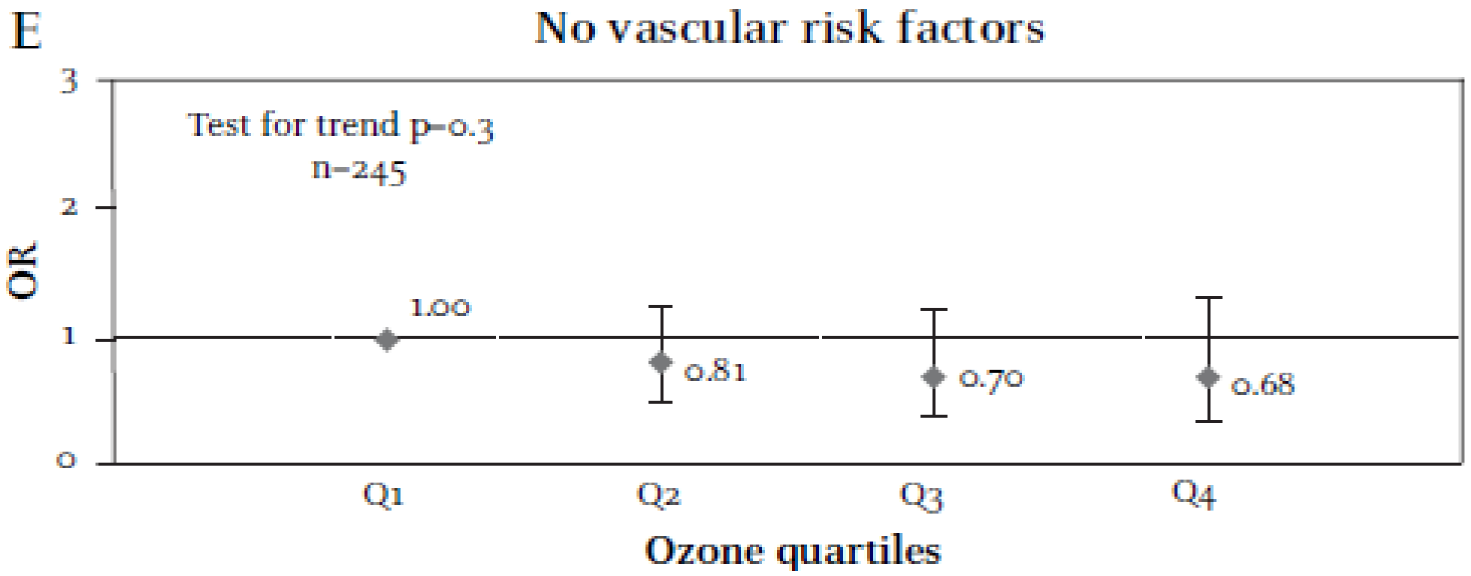
Ambient air pollution and stroke

Short-term exposure

Ozone pollution

Henrotin JB, Heart 2010;96:1190-1996

Dose-response relationship (with 1-day lag) between O3 quartiles and ischemic events



Short-term exposure

Henrotin JB, Heart 2010;96:1190-1996

Ozone pollution

	O_3 (µg/m³)	Sunlight (min/day)	Wind (m/s)§	Temperature (°C)†	Humidity (%)‡	PM_{10} (µg/m³)	SO_2 (µg/m³)	CO (µg/m³)	NO_2 (µg/m³)
Mean	38.2	315.9	3.53	15.1	93.2	20.5	3.4	456	36.0
SD	24.4	273.5	1.58	8.9	6.9	11.6	3.0	274	14.3
Median	37	263	3	16.3	96	18	3	392	35
Minimum	0	0	0	−4.5	51	0	0	0	6
Maximum	123	910	10	39.3	100	90	24	2265	110

Objectives	Value	Measured as	Target/action
Information threshold	180 µg/m³	Hourly average	National authorities should inform the public and give advice immediately after an exceedance. Countries should report monthly on all exceedances
Alert threshold	240 µg/m³	Hourly average	National authorities should inform the public and give advice immediately after an exceedance. Countries should report monthly on all exceedances
Protect Human health	120 µg/m³	8 Hour average	Not to be exceeded on more than 25 days per year

Source: European Environment Agency

DIJON STROKE REGISTRY

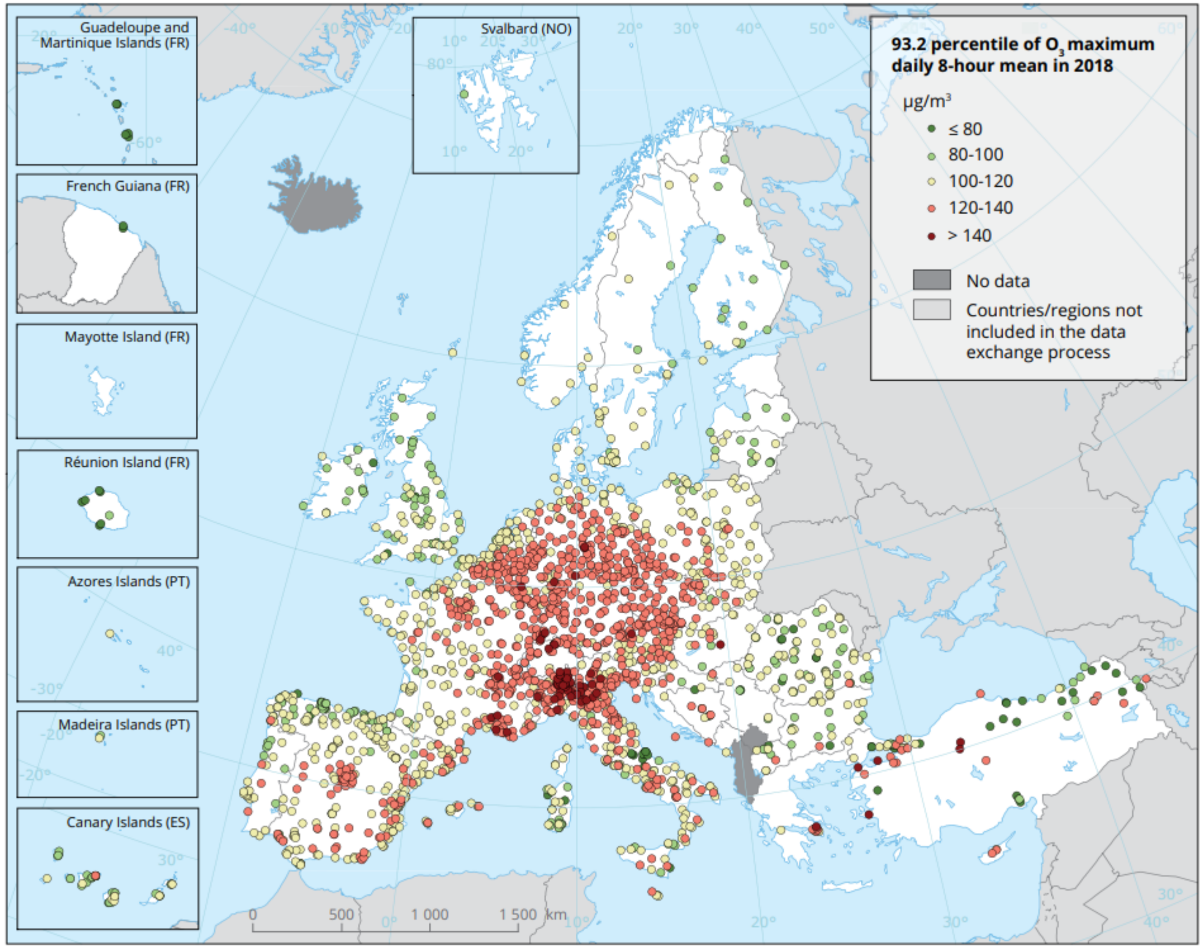
RICO

Ambient air pollution and stroke

Short-term exposure

Ozone pollution

Map 5.1 Concentrations of O_3 in 2018



Reference data: ©ESRI | ©EuroGeographics

Source: European Environment Agency

Figure ES.1 Key numbers

Pollutant	Year	EU-28 urban population exposure to concentrations **above** EU standards (¹)	Urban population exposure to concentrations **above** WHO AQG value (²)	Reporting stations that registered concentrations **above** EU standards (¹)	Reporting stations that registered concentrations **above** WHO AQG value (²)
PM_{10}	2018	15 %	48 %	19 % 20 EU MS (EU-28) and six other countries	53 % All countries except Estonia, Iceland and Ireland
	2019 (preliminary) for 30 countries	(*)	(*)	9 % 13 EU MS and two other countries	37 % All countries except Estonia, Finland, Iceland, Ireland and Luxembourg
$PM_{2.5}$	2018	4 %	74 %	4 % Six EU MS and two other countries	70 % All countries except Estonia, Finland Iceland and Ireland
	2019 (preliminary) for 27 countries	(*)	(*)	2 % 4 EU MS and two other countries	58 % All countries except Estonia, Finland, Iceland, Ireland, Luxembourg, Norway and Sweden
O_3	2018	34 %	99 %	41 % 20 EU MS and five other countries	96 %
	2019 (preliminary) for 32 countries	(*)	(*)	27 % 18 EU MS and two other countries	98 %
NO_2	2018	4 % (³)	4 % (³)	8 % 16 EU MS and three other countries (³)	8 % 16 EU MS and three other countries (³)
	2019 (preliminary) for 33 countries	(*)	(*)	3 % 12 EU MS and one other country (³)	3 % 12 EU MS and one other country (³)
BaP	2018	15 %	75 %	27 % 14 EU MS	83 % All countries except Cyprus.
	2019 (preliminary)	(*)	(*)	(⁴)	(⁴)
SO_2	2018	<1 %	19 %	<1 % One EU MS and three other countries	33 % 27 countries
	2019 (preliminary) for 32 countries	(*)	(*)	<1 % One EU MS	28 % 22 countries

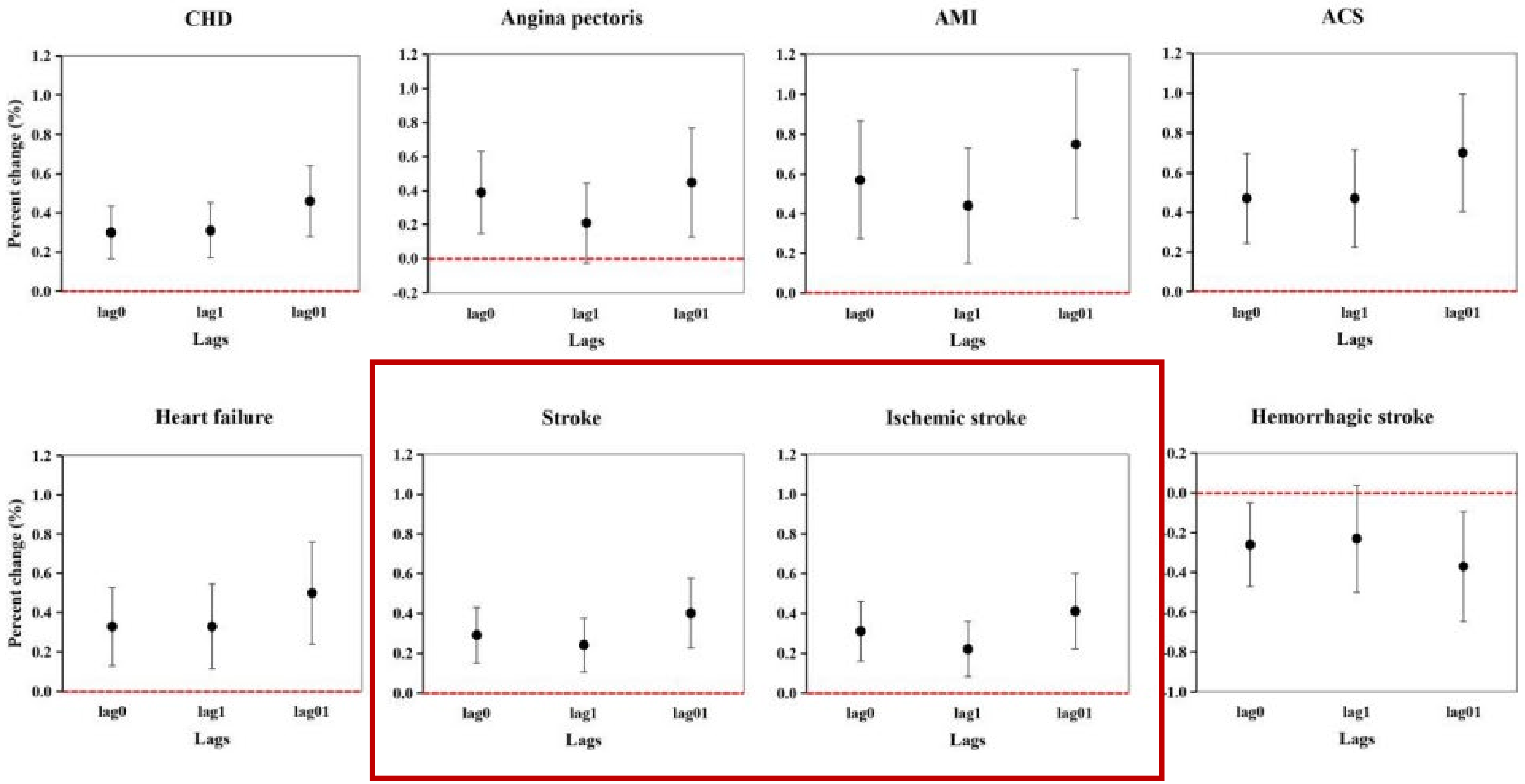
Air quality in Europe - 2020 report EEA Report No 09/2020

Ambient air pollution and stroke

Short-term exposure

Ozone pollution

Jiang Y, Eur Heart J. 2023;44(18):1622-1632



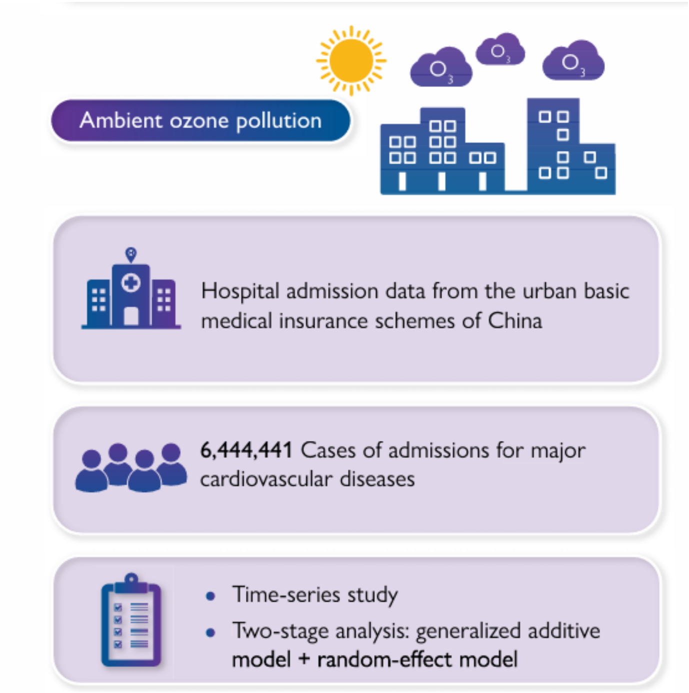
% change in daily hospital per 10 µg/m3 increase in daily ambient 8-h maximum ozone concentration

Ambient air pollution and stroke

Short-term exposure

Ozone pollution

Jiang Y, Eur Heart J. 2023;44(18):1622-1632



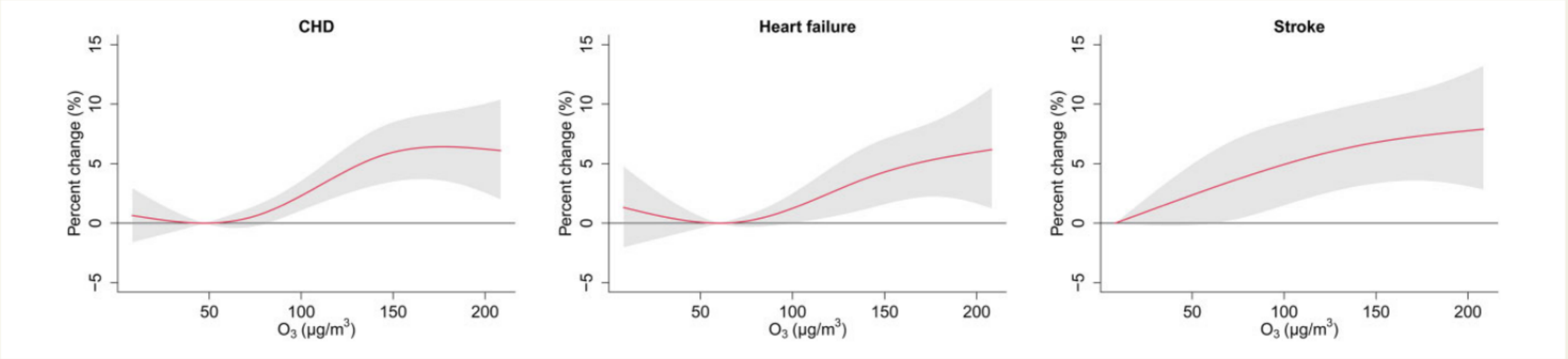


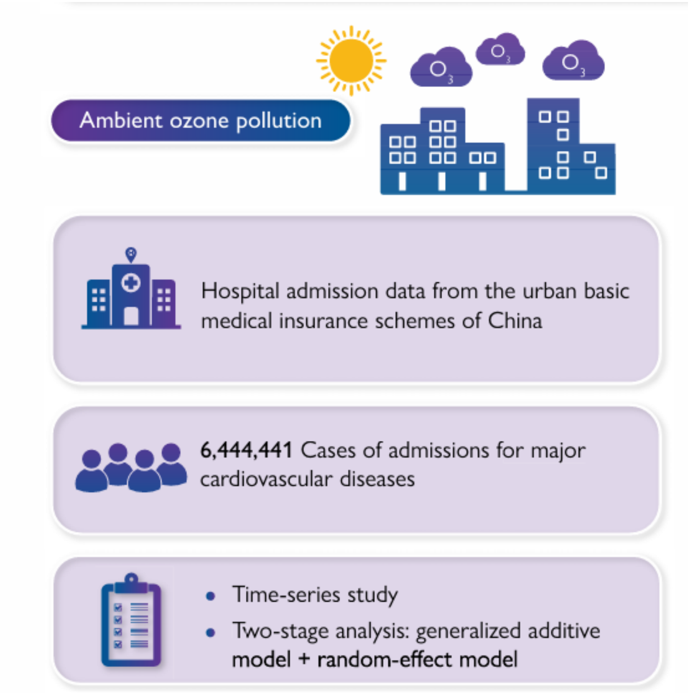
Figure 2 The exposure–response curves for the associations of daily ambient 8-h maximum ozone with hospital admissions for coronary heart disease, heart failure, and stroke over the cumulative lags of 0 to 1 days in the 70 Chinese cities during 2015–17. Note: the solid lines are the percent changes in hospital admissions for cardiovascular events and the gray areas are the 95% confidence intervals. Abbreviations: CHD, coronary heart disease; O_3, ozone.

Ambient air pollution and stroke

Short-term exposure

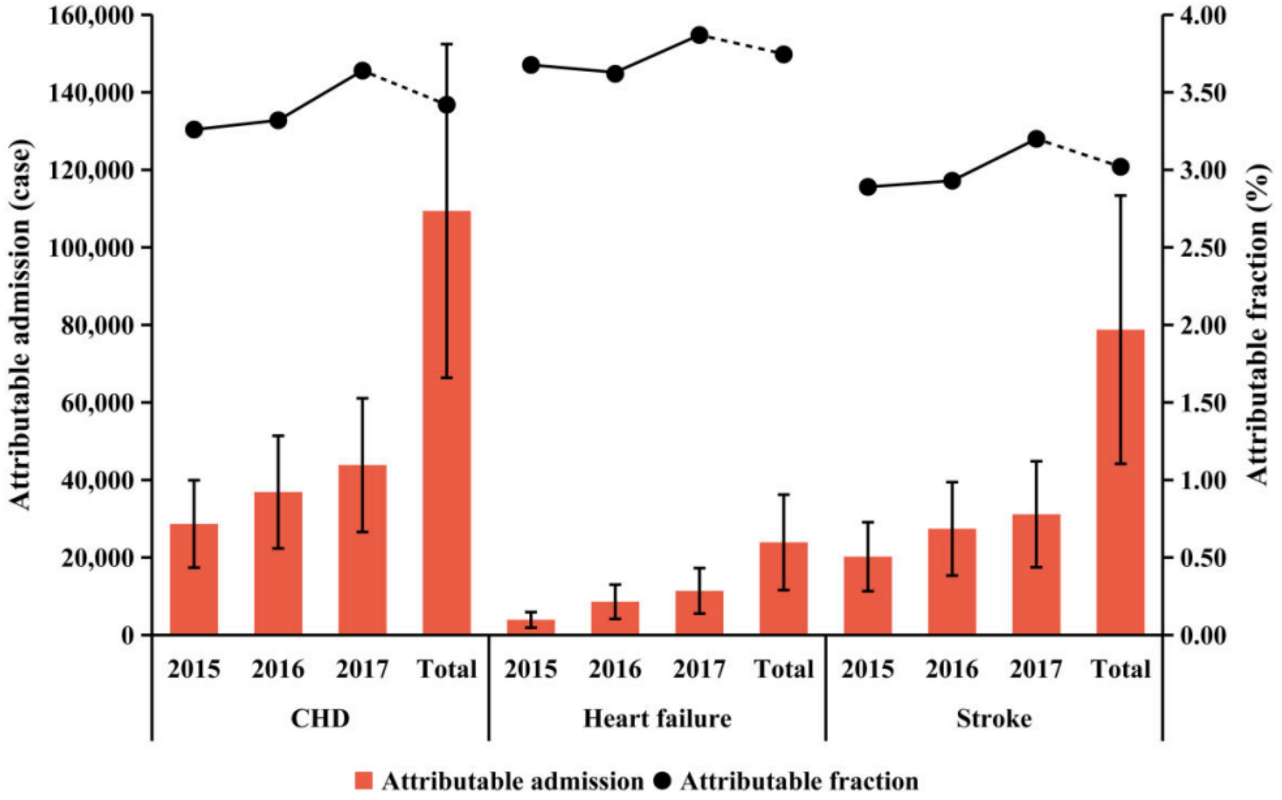
Ozone pollution

Jiang Y, Eur Heart J. 2023;44(18):1622-1632



Attributable numbers of **stroke** during 2015– 2017

78 784 (95% CI: 44,182, 112,903)



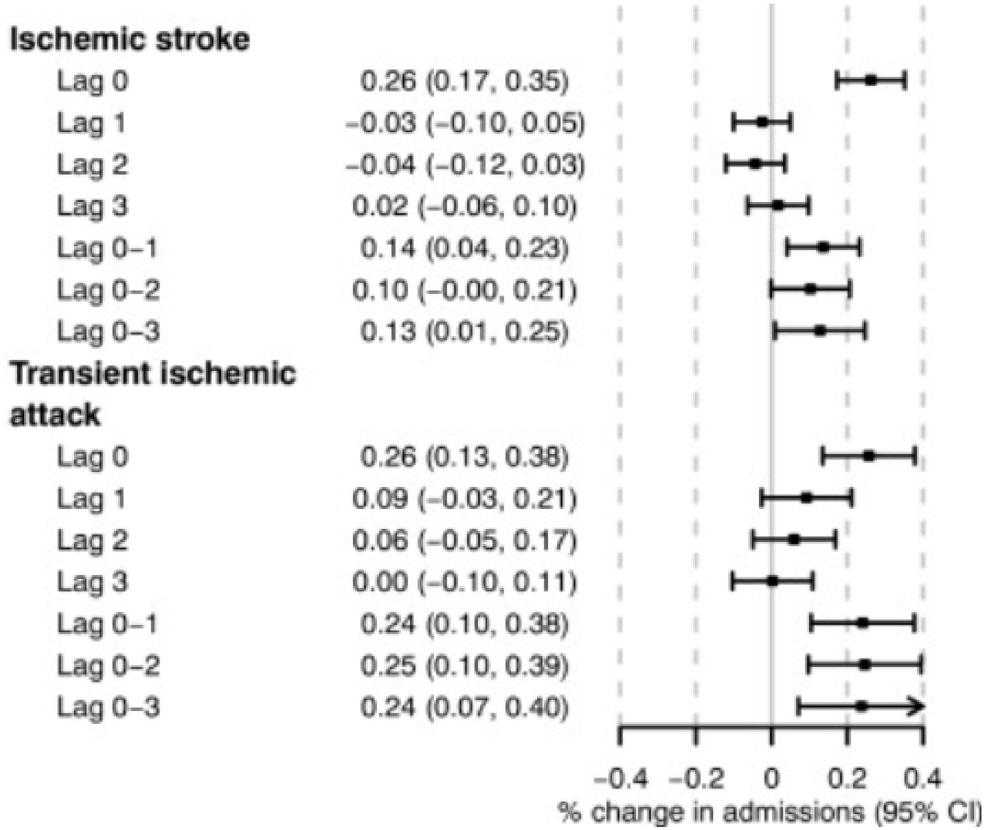
Ambient air pollution and stroke

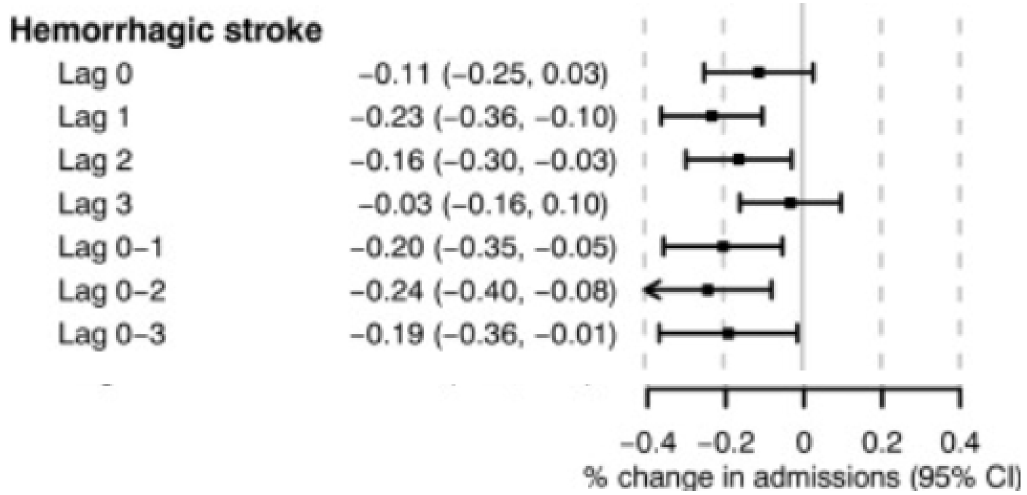
Short-term exposure

$PM_{2.5}$

Gu J, Sci Total Environ. 2020;715:136896.

8,359,162 hospital admissions in 248 Chinese cities from 2013 to 2017





Per 10 μg/m³ increase in **$PM_{2.5}$ concentration**

Ambient air pollution and stroke

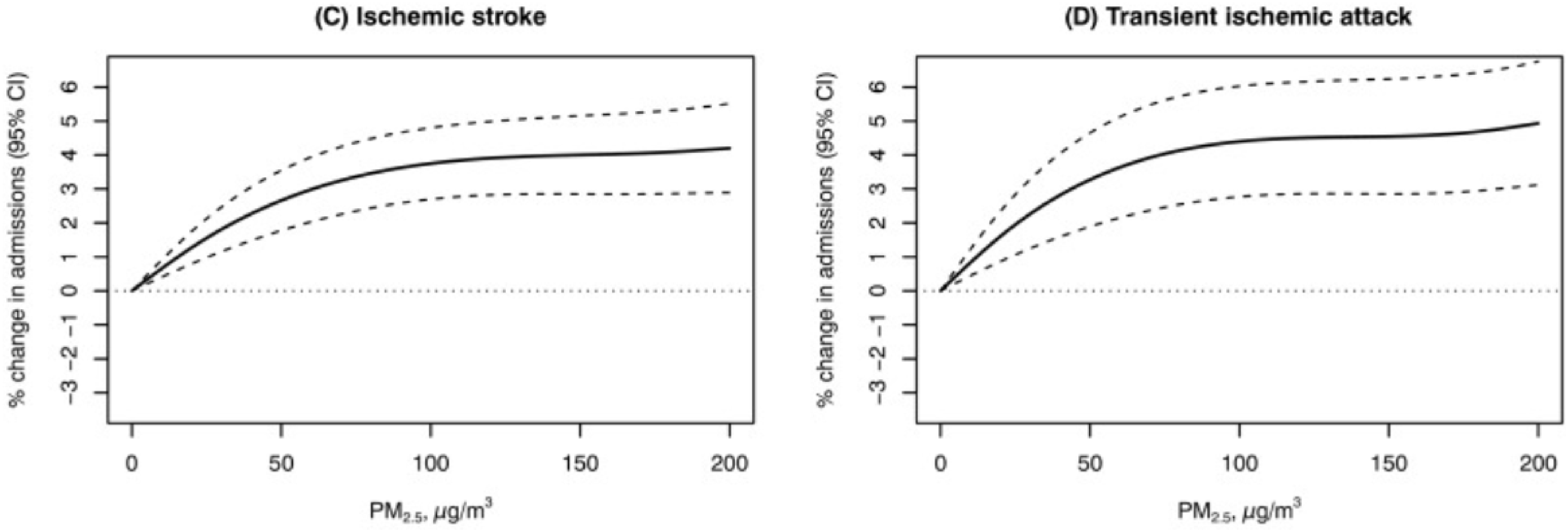
Short-term exposure

$PM_{2.5}$

Gu J, Sci Total Environ. 2020;715:136896.

8,359,162 hospital admissions in 248 Chinese cities from 2013 to 2017

Exposure-response curves of the effects of $PM_{2.5}$ (lag 0 day) on hospital admissions

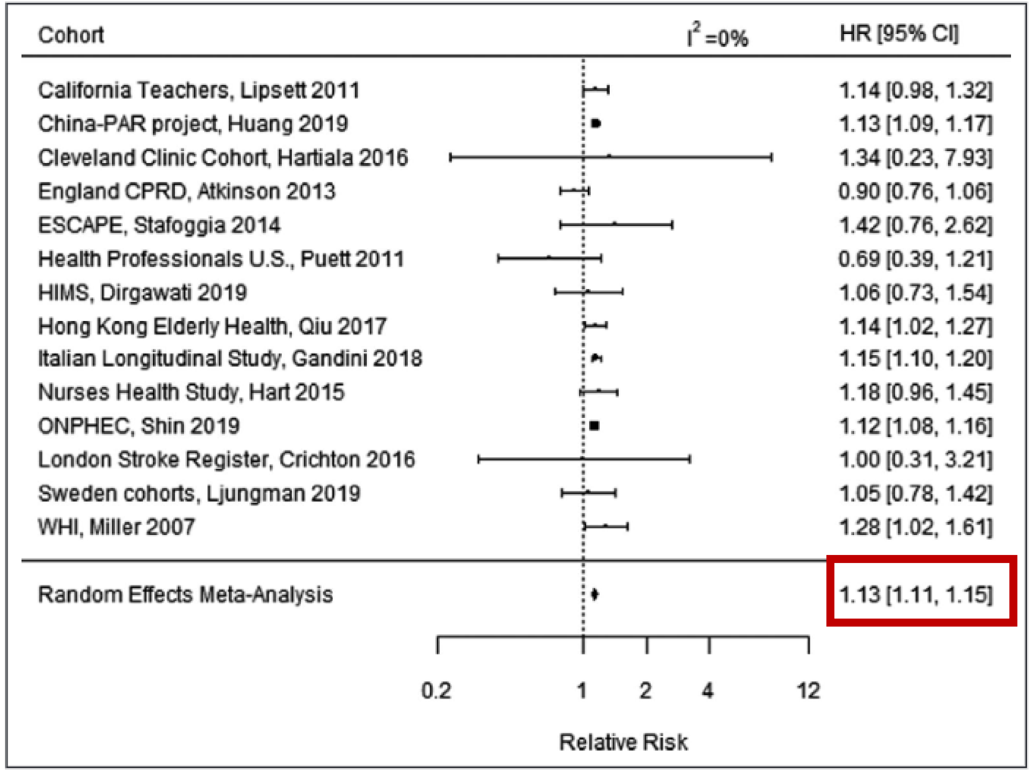


Ambient air pollution and stroke

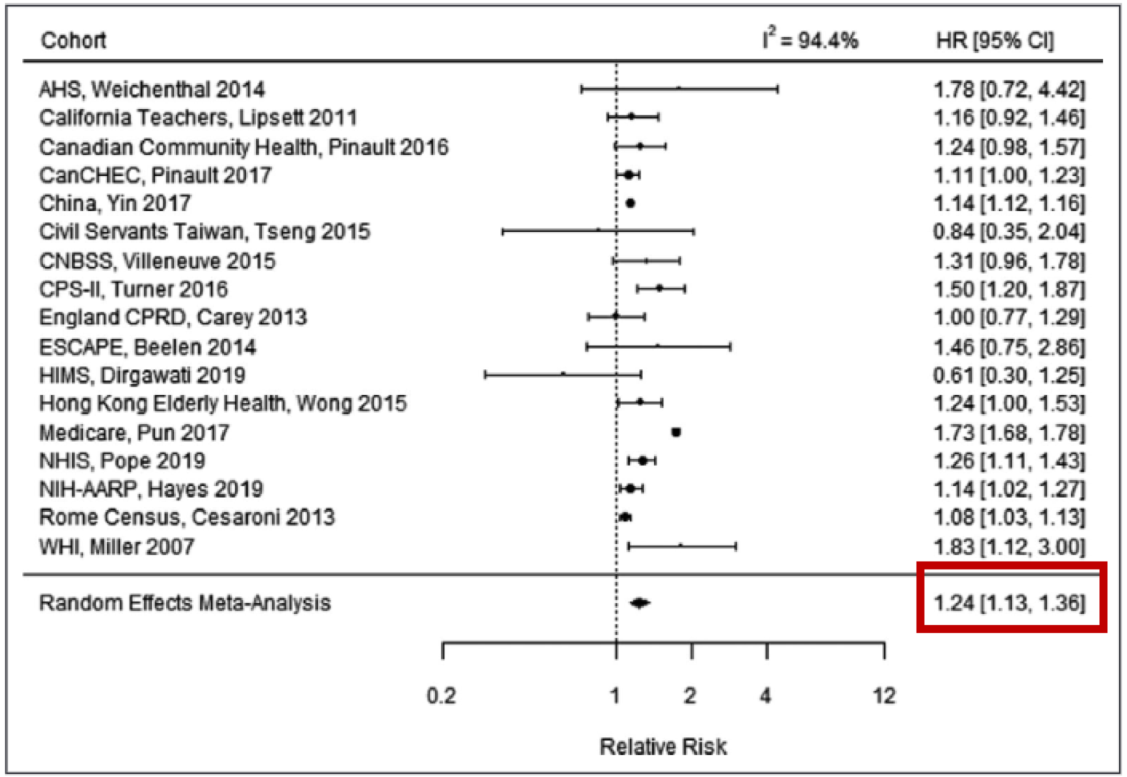
Long-term exposure

Alexeeff S, J Am Heart Assoc. 2021;10:e016890.

Incident stroke



Cerebrovascular mortality



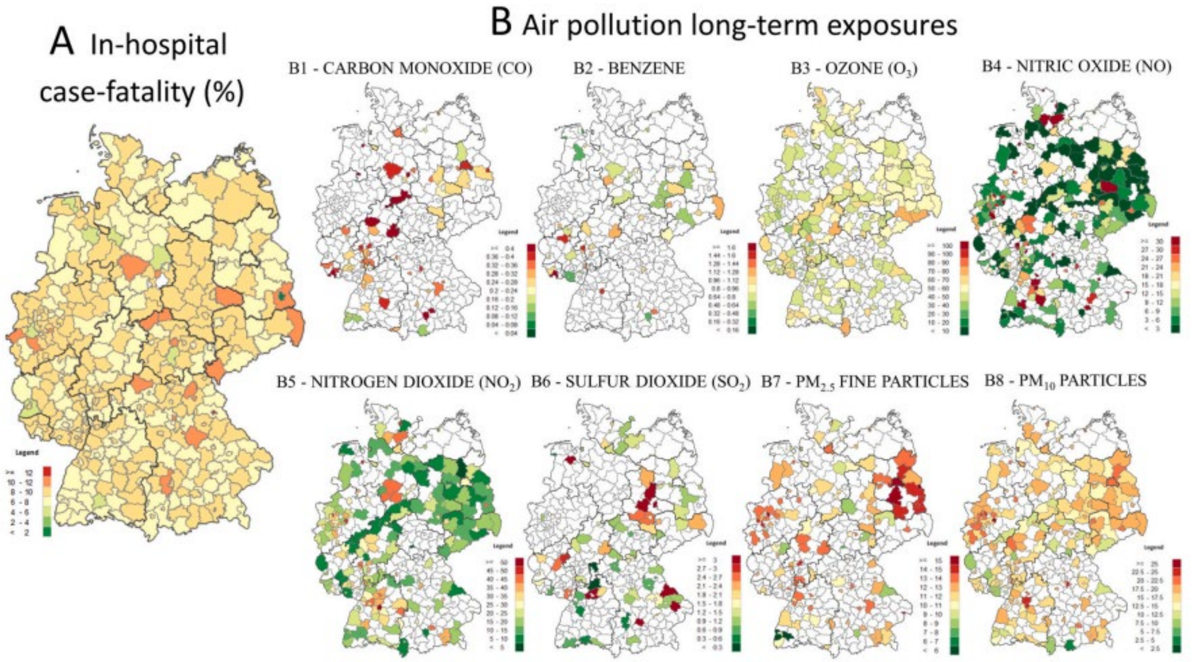
per 10-µg/m3 increase in long-term fine particulate matter <2.5 µm in diameter exposure

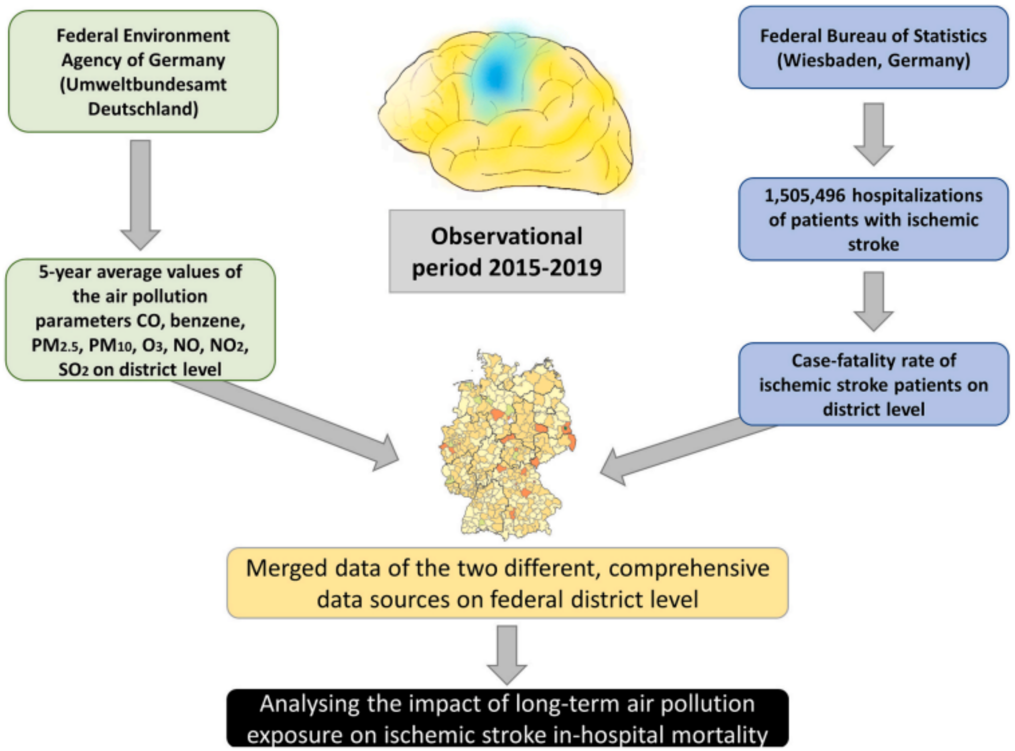
Ambient air pollution and stroke

Long-term exposure

Keller K, Thromb Res 2023 ;S0049-3848(23)00080-4..

- German nationwide inpatient sample
- 1.5 millions patients hospitalisés pour infarctus cerebral en Allemagne (2015-2019)
- Données pollution selon lieu de residence (German Federal Environmental Agency)



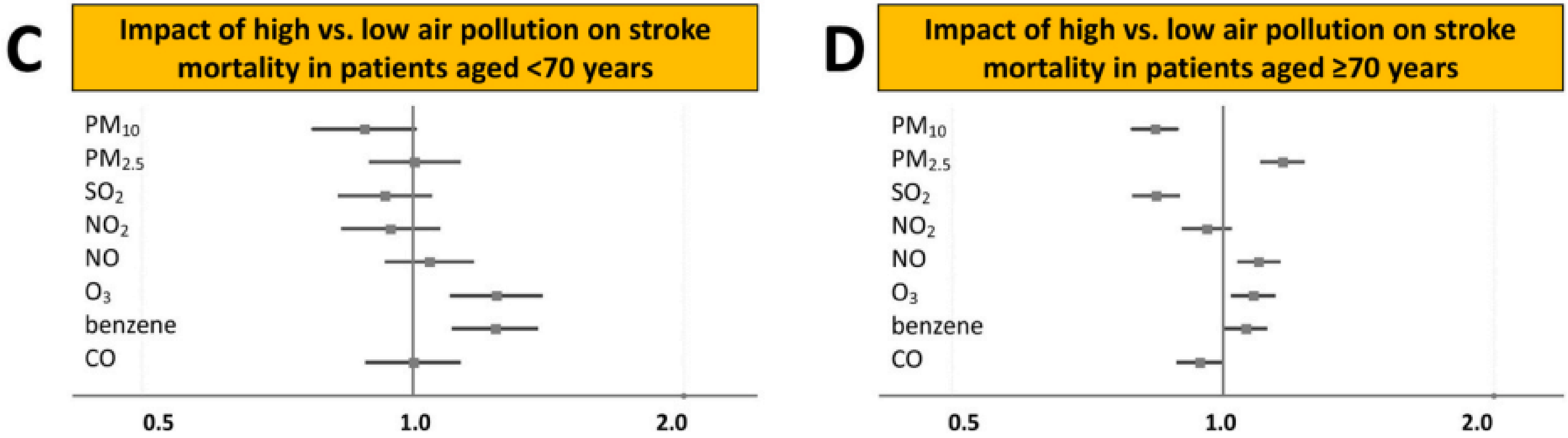


Ambient air pollution and stroke

Long-term exposure

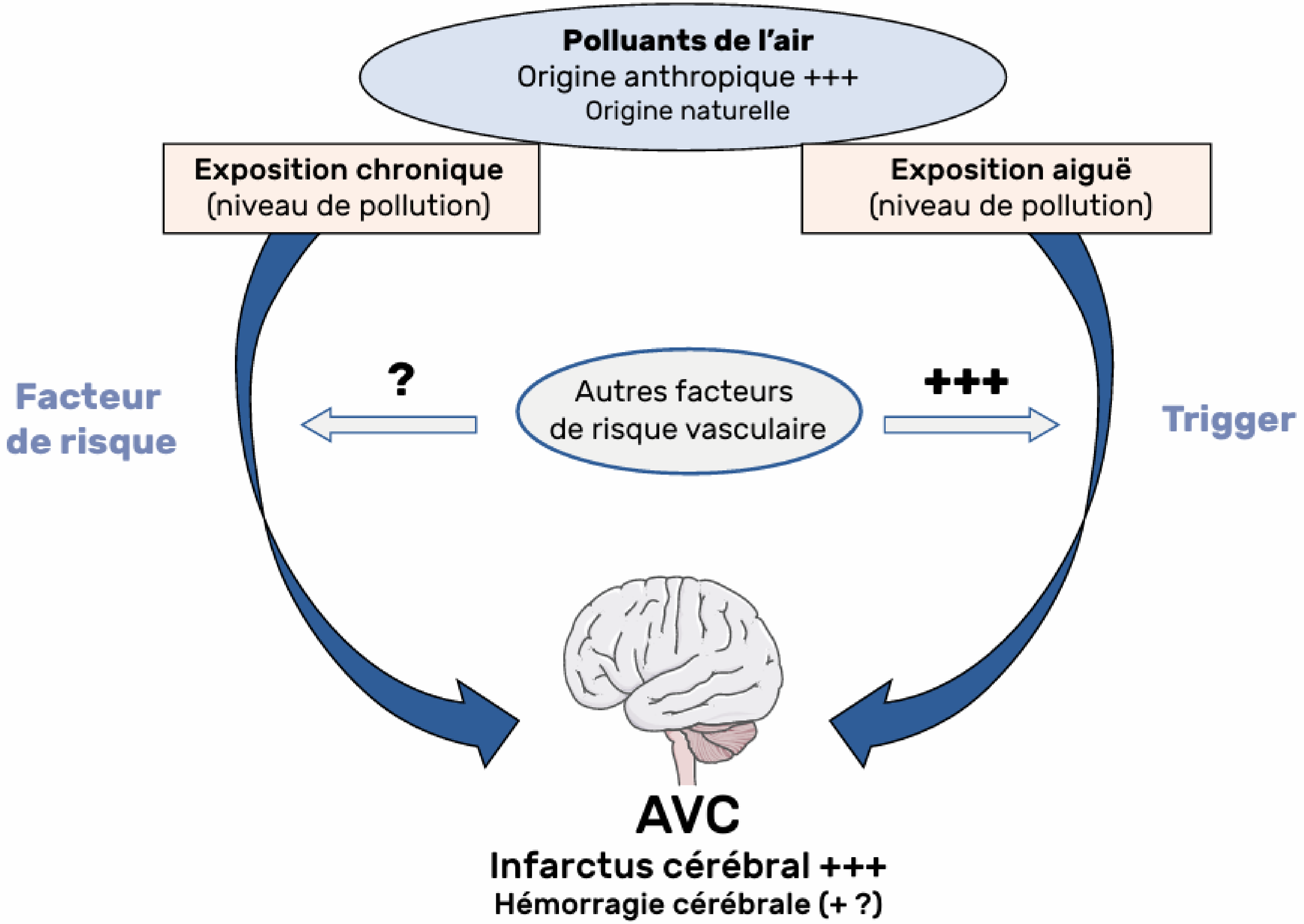
Keller K, Thromb Res 2023 ;S0049-3848(23)00080-4..

- In-hospital mortality



Ambient air pollution and stroke

Béjot Y, Neurologies 2024;258:118-122.



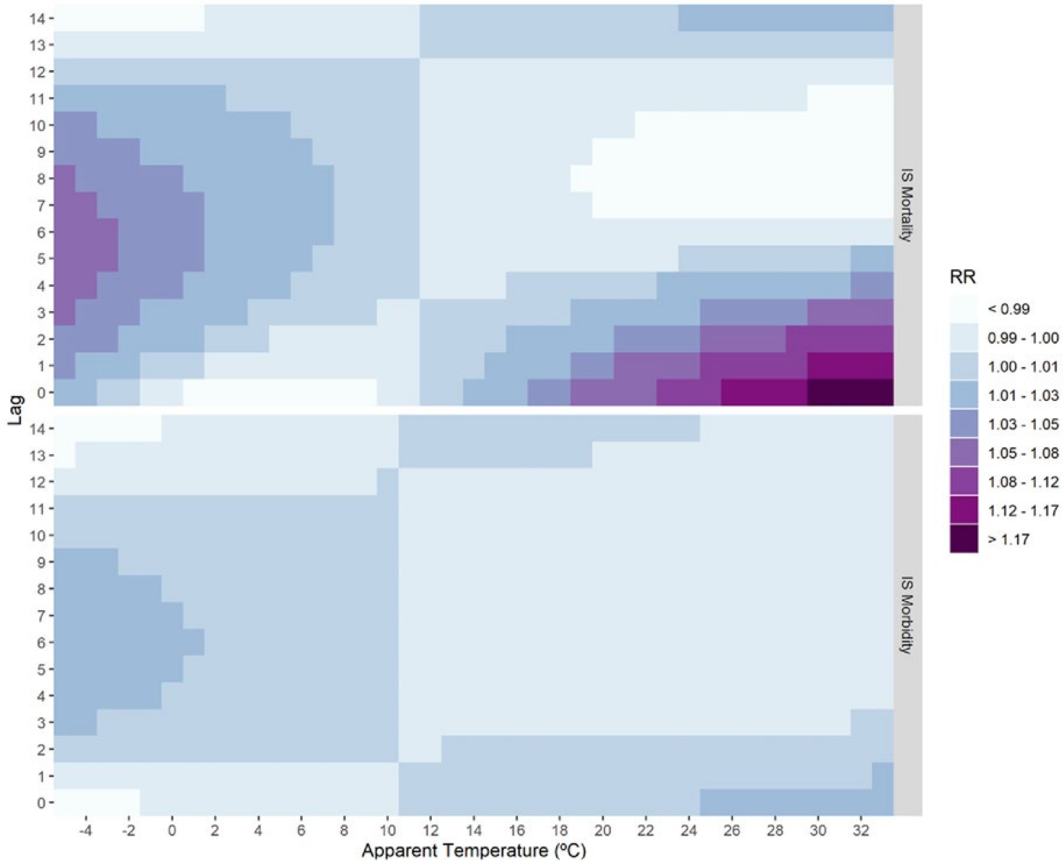
Extreme temperatures and stroke

- Study in Madrid, Spain, including 106,036 IS hospital admissions
- Daily apparent temperatures

Royé D, Environ Res. 2019:173:349-358

IS mortality

IS hospital admissions

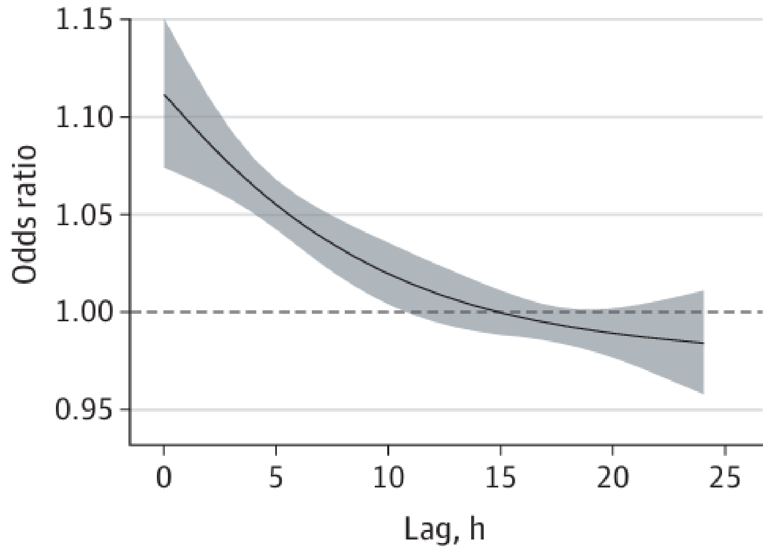


Extreme temperatures and stroke

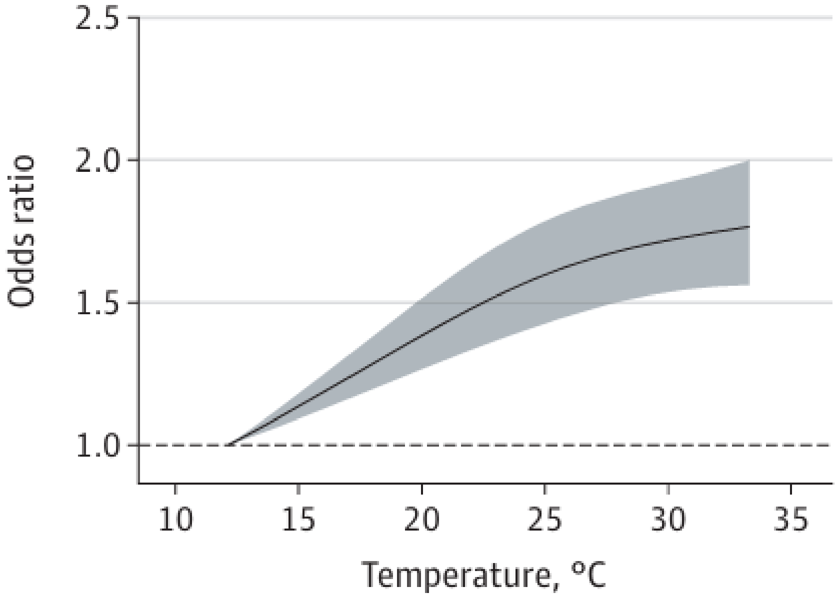
- Time-stratified case-crossover study in China - 82 455 patients with acute IS
- Hourly temperature

Zhu X, JAMA Netw Open. 2024;7:e240627

Association between IS and extremely high temperature (99th percentile of the temperature distribution)



Association between ambient temperature and IS accumulated over 0 to 10 hours

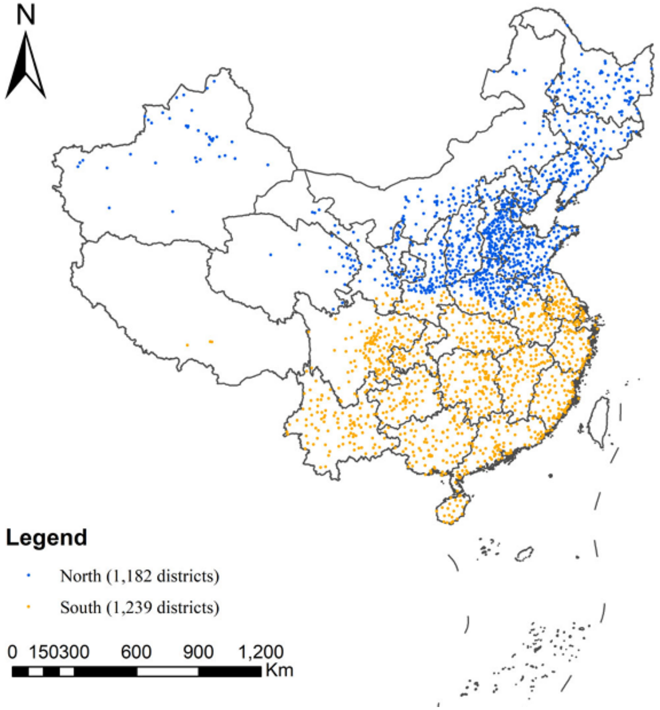


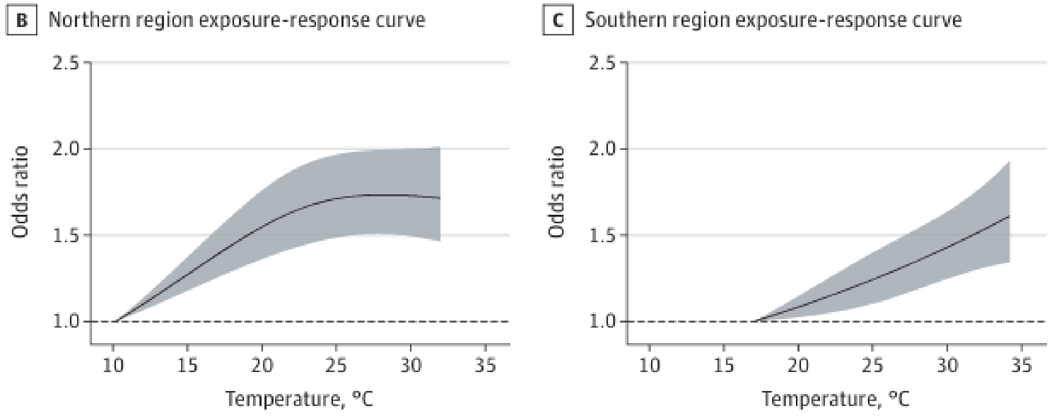
Transient exposure to high temperature associated with IS
Association occurring at the concurrent hour and lasting for up to 10 hours

Extreme temperatures and stroke

- Time-stratified case-crossover study in China - 82 455 patients with acute IS
- Hourly temperature

Zhu X, JAMA Netw Open. 2024;7:e240627





Characteristic	Case, No. (%)	Temperature, °C		OR (95% CI)	*P* value for z score
		Extremely high	Reference		
National level	82 455 (100.0)	33.3	12.1	1.88 (1.65-2.13)	NA
Regional level					
North	46 550 (56.5)	32.0	10.2	1.80 (1.53-2.11)	.27
South	35 905 (43.5)	34.2	17.1	1.57 (1.31-1.87)	

Association was greater in magnitude in the north than in the south

Extreme temperatures and stroke

- Time-stratified case-crossover study in China - 82 455 patients with acute IS
- Hourly temperature

Zhu X, JAMA Netw Open. 2024;7:e240627

Characteristic	Case, No. (%)	Temperature, °C		OR (95% CI)	*P* value for z score
		Extremely high	Reference		
National level	82 455 (100.0)	33.3	12.1	1.88 (1.65-2.13)	NA
History of other disease[e]					
No history of other disease	27 952 (33.9)	33.2	12.1	1.94 (1.58-2.38)	NA
History of hypertension	49 259 (59.7)	33.4	12.2	1.80 (1.53-2.12)	.59[f]
History of dyslipidemia	2433 (3.0)	33.2	12.1	$\boxed{4.68 (2.15\text{-}10.17)}$	.68[f]
History of atrial fibrillation	2794 (3.4)	33.5	12.6	2.17 (0.86-4.34)	.80[f]

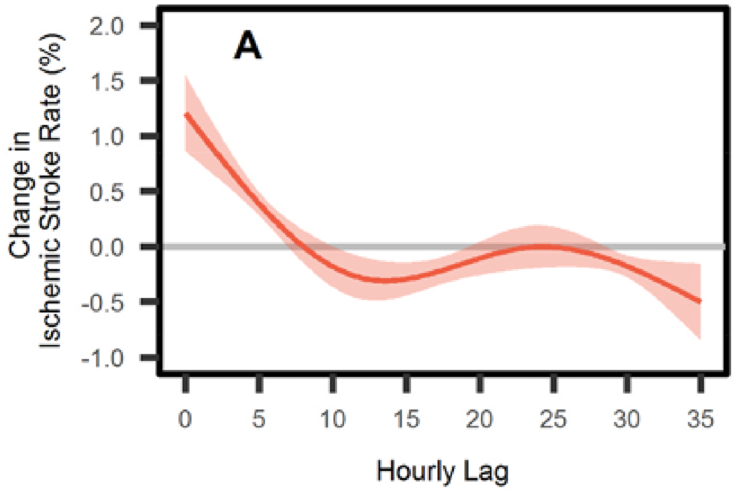
Trends toward higher ORs among patients with dyslipidemia

Extreme temperatures and stroke

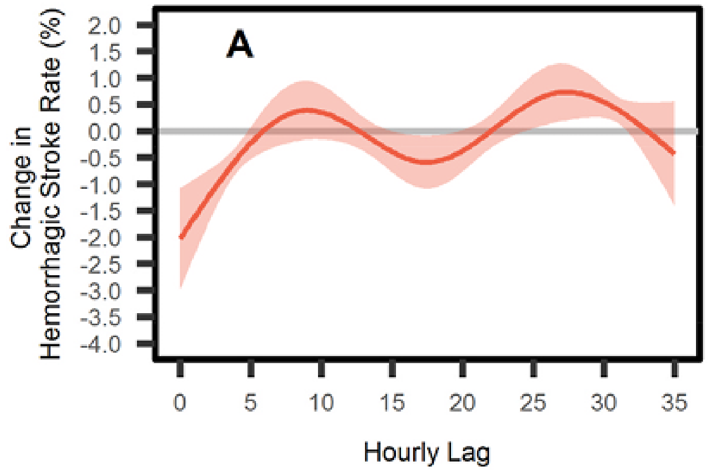
- Time-stratified case-crossover study in New York - 578,181 ischemic and 164,755 hemorrhagic strokes.
- Hourly temperature

Rowland ST, Environ Res. 2022;207:112229

Ischemic stroke



Hemorrhagic stroke



percent increase in the hourly stroke rate for a 10°C increase in hourly temperature for each lag

A 10°C increase over 7 h was associated with 5.1% increase in hourly ischemic stroke rate
Temperature negatively associated with hemorrhagic stroke over 5 hours

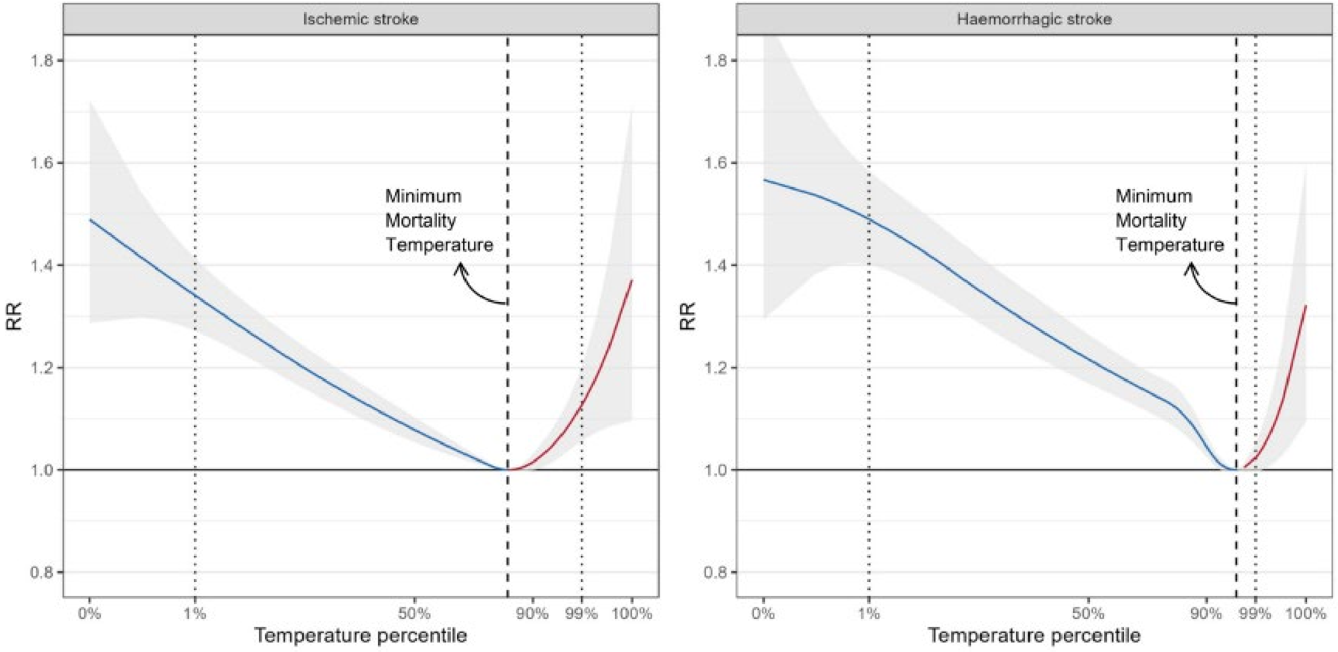
Extreme temperatures and stroke

Alahmad B, Stroke. 2024;55:1847-1856

- 3 443 969 ischemic and 2 454 267 hemorrhagic **stroke deaths**
- from 522 cities in 25 countries

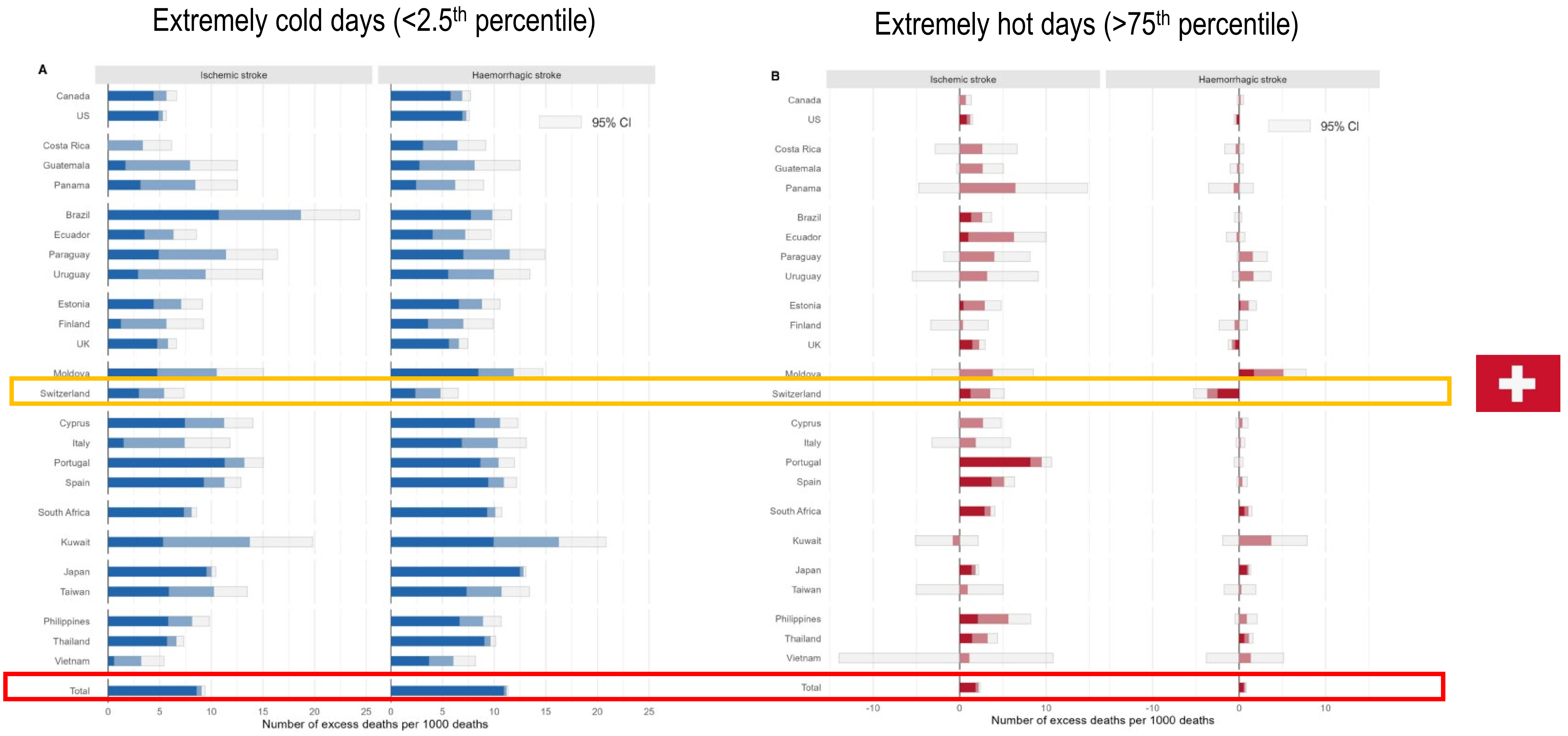
Country	Stroke data source	Years	Cities	Ischemic stroke	Hemorrhagic stroke	Temp. mean (°C)	Temp. SD (°C)
Brazil	Ministry of Health	1997–2018	9	146 180	97 044	23.4	4.2
Canada	Canadian Mortality Database	1986–2015	26	92 448	56 242	6.8	10.9
Costa Rica	Instituto Nacional de Estadistica y Censos	2000–2017	1	655	516	22.7	1.1
Cyprus	Causes of Death Database, Health Monitoring Unit, Ministry of Health	2004–2017	5	3954	981	20.4	6.2
Ecuador	Instituto Nacional de Estadistica y Censos	2013–2019	2	3857	4806	21.0	5.4
Estonia	Estonian Causes of Death Registry	1997–2018	8	23 637	5385	6.2	8.9
Finland	Statistics Finland	1987–2018	1	10 302	5791	5.9	9.0
Guatemala	Instituto Nacional de Estadistica, Unidad de Estadistica de Salud	2009–2018	1	1162	916	19.4	1.6
Italy	Regional mortality registry of the Lazio Region	2006–2015	4	2110	8315	16.3	7.4
Japan	Ministry of Health, labor and Welfare	1979–2015	47	1 845 428	1 584 972	15.2	8.6
Kuwait	National Center for Health Information, Ministry of Health	2000–2016	1	4432	1937	27.1	9.8
Moldova	National Center for Health Management	2001–2010	1	2289	5581	10.8	9.8
Panama	Instituto Nacional de Estadistica y Censo, Centro de Información Estadística.	2013–2016	1	118	219	28.1	1.1
Paraguay	Ministerio de Salud Pública y Bienestar Social, Dirección General de Información Estratégica en Salud	2004–2019	1	995	1248	23.3	5.3
Philippines	Philippine Statistics Agency	2006–2010	4	14 738	12 476	28.2	1.4
Portugal	Statistics Portugal	1990–2018	6	69 742	26 810	16.3	5.4
South Africa	Statistics South Africa	1997–2013	51	337 559	45 655	18.0	5.4
Spain	Spain National Institute of Statistics	2000–2018	6	51 033	25 615	17.1	6.6
Switzerland	Federal Office of Statistics (Switzerland)	1995–2016	8	39 057	10 705	10.5	7.5
Taiwan	Department of Health in Taiwan	2008–2016	3	10 544	11 079	24.1	5.1
Thailand	Ministry of Public Health	1999–2008	55	25 996	76 675	27.6	2.4
United Kingdom	Office of National Statistics	1990–2016	70	203 401	87 947	10.5	5.3
Uruguay	Ministerio de Salud Publica	2001–2018	1	14 565	6558	18.6	5.6
United States	National Center for Health Statistics	1985–2006	209	534 701	373 350	14.1	10.1
Vietnam	Provincial Department of Health, Ho Chi Minh	2010–2013	1	5066	3444	28.5	1.4
Total		1979–2019	522	3 443 969	2 454 267		

Pooled exposure-response relationships between overall temperature percentiles and relative risk of stroke



Extreme temperatures and stroke

Alahmad B, Stroke. 2024;55:1847-1856

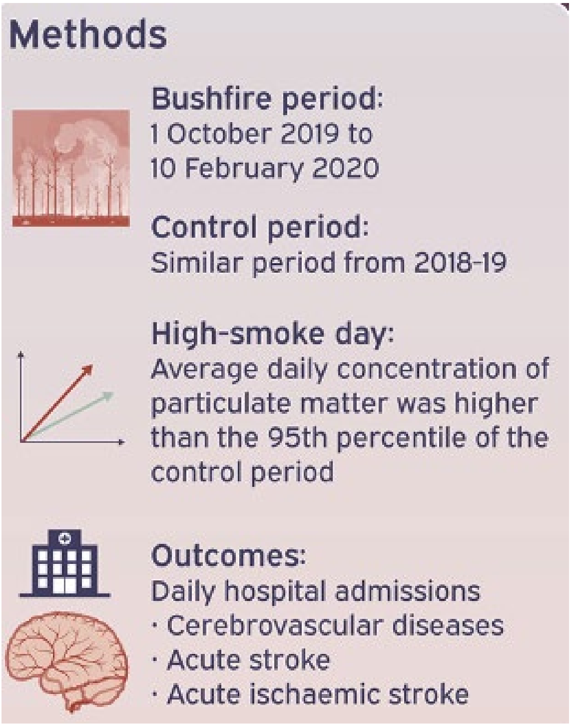


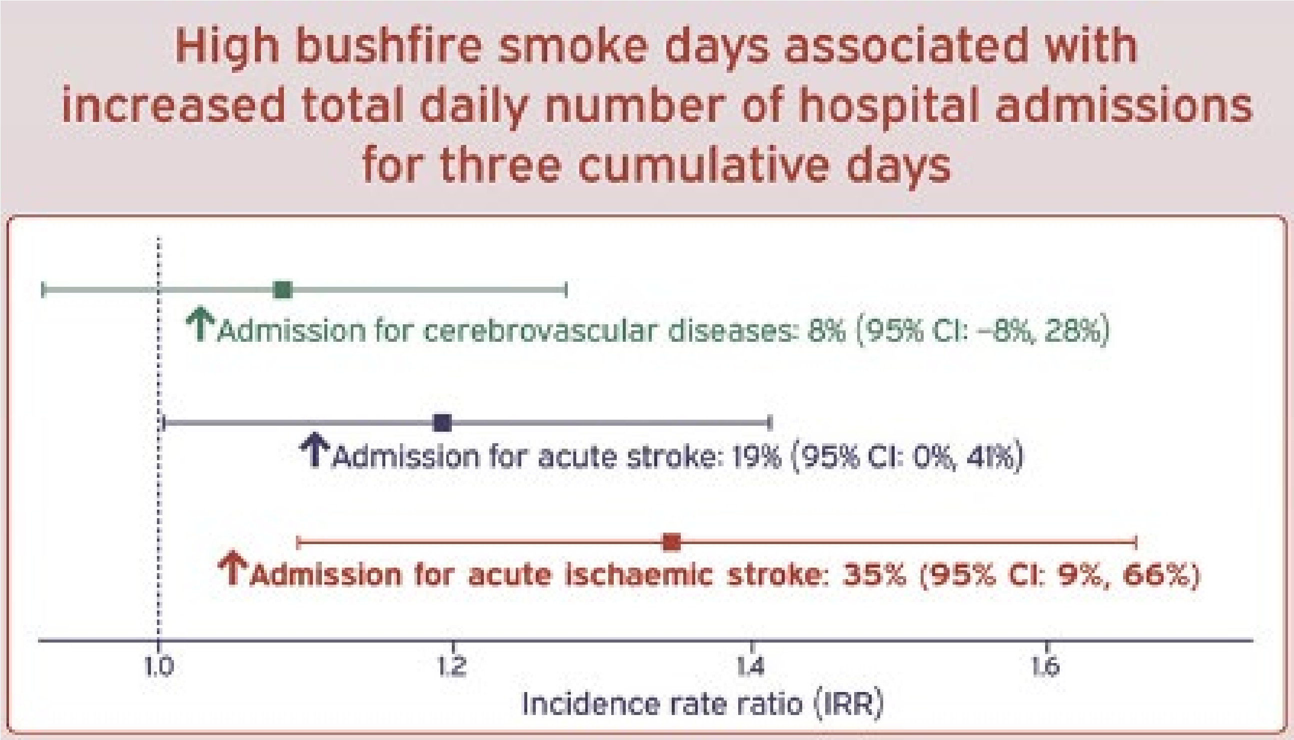
Other consequences of climate change

Wildfires

2019–20 bushfire in Australia

Hasnain MD, Eur Stroke J. 2024:23969873231223307





Other consequences of climate change

Wildfires

Hasnain MD, Eur Stroke J. 2024:23969873231223307

2019–20 bushfire in Australia

Daily hospital admissions ischaemic stroke across lag 0–3 days

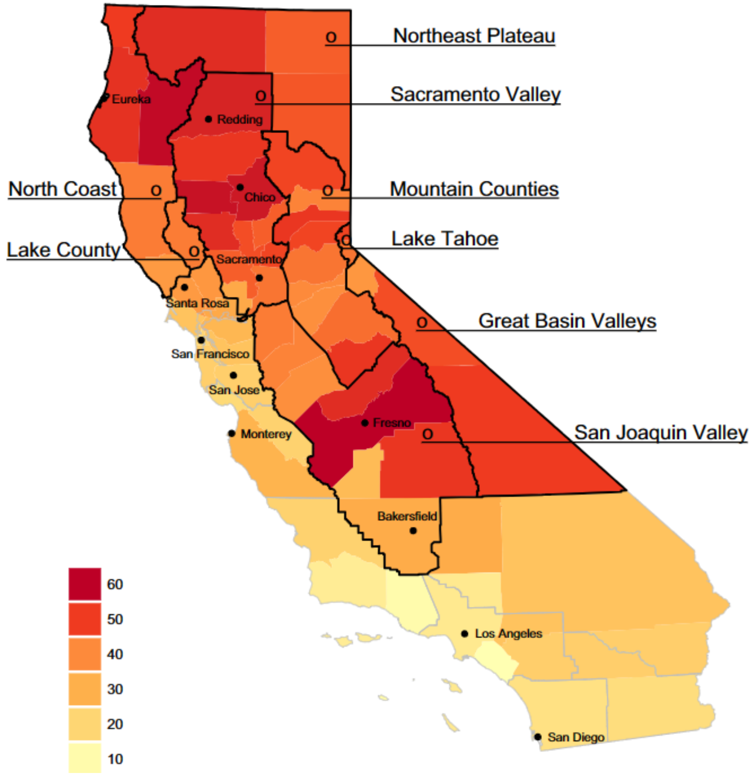
	Control period IRR (95% CI); *p*-value	Bushfire period IRR (95% CI); *p*-value
PM_{10} acute ischaemic stroke		
Same day	0.99 (0.97–1.01); 0.39	1.01 (1.00–1.02); 0.01*
1 day lag	0.99 (0.96–1.02); 0.42	1.01 (1.00–1.02); 0.03*
2 day lag	0.99 (0.96–1.01); 0.33	1.01 (1.00–1.02); 0.01*
3 day lag	0.99 (0.97–1.02); 0.49	1.01 (1.00–1.02); 0.01*
$PM_{2.5}$ acute ischaemic stroke		
Same day	0.95 (0.86–1.06); 0.35	1.01 (1.00–1.03); 0.11
1 day lag	0.93 (0.82–1.04); 0.20	1.02 (1.00–1.03); 0.08
2 day lag	0.92 (0.82–1.04); 0.20	1.02 (1.00–1.03); 0.03*
3 day lag	0.92 (0.81–1.03); 0.16	1.02 (1.00–1.03); 0.06

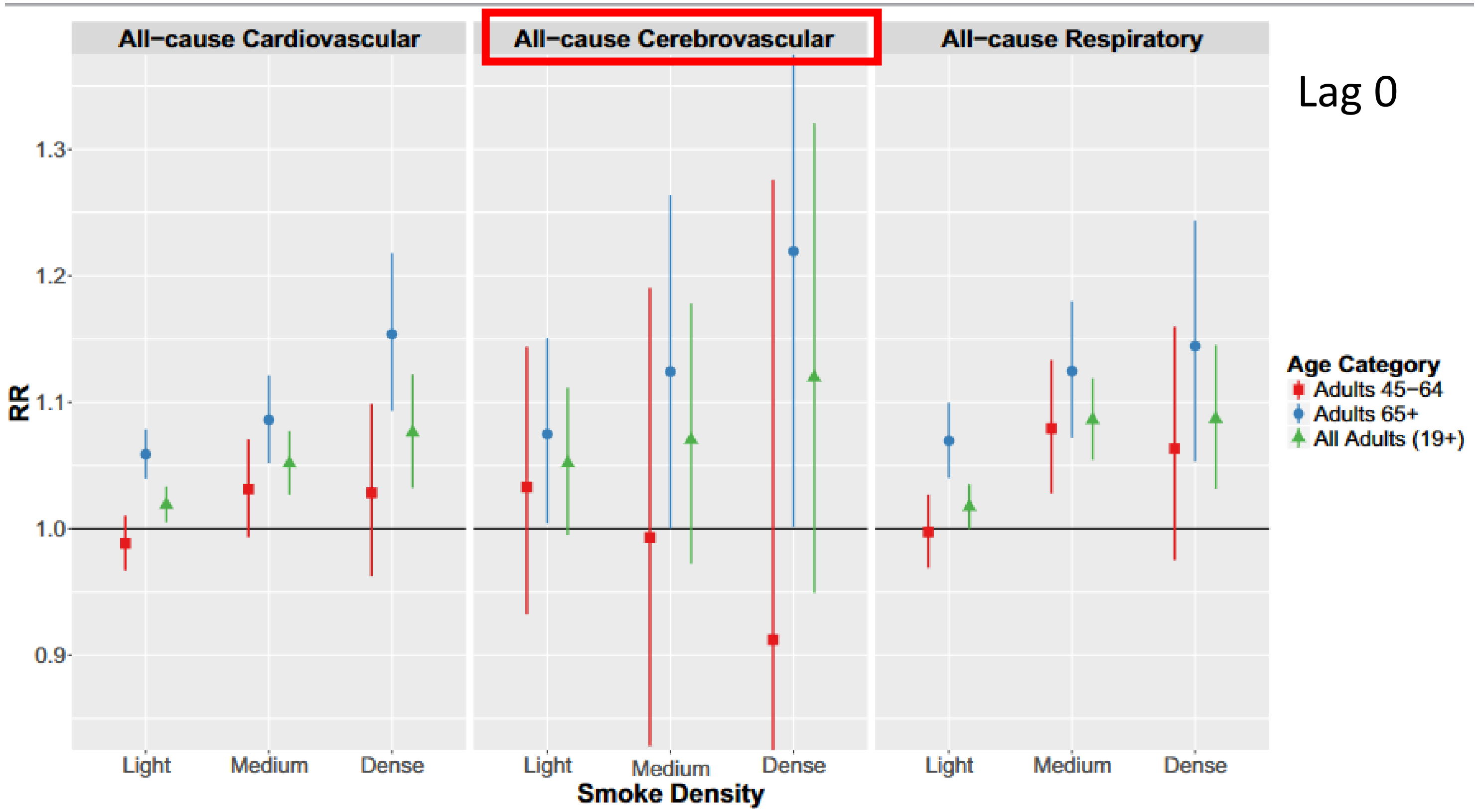
Other consequences of climate change

Wildfires

Wettstein ZS, J Am Heart Assoc. 2018;7:e007492

2015 wildfires in California



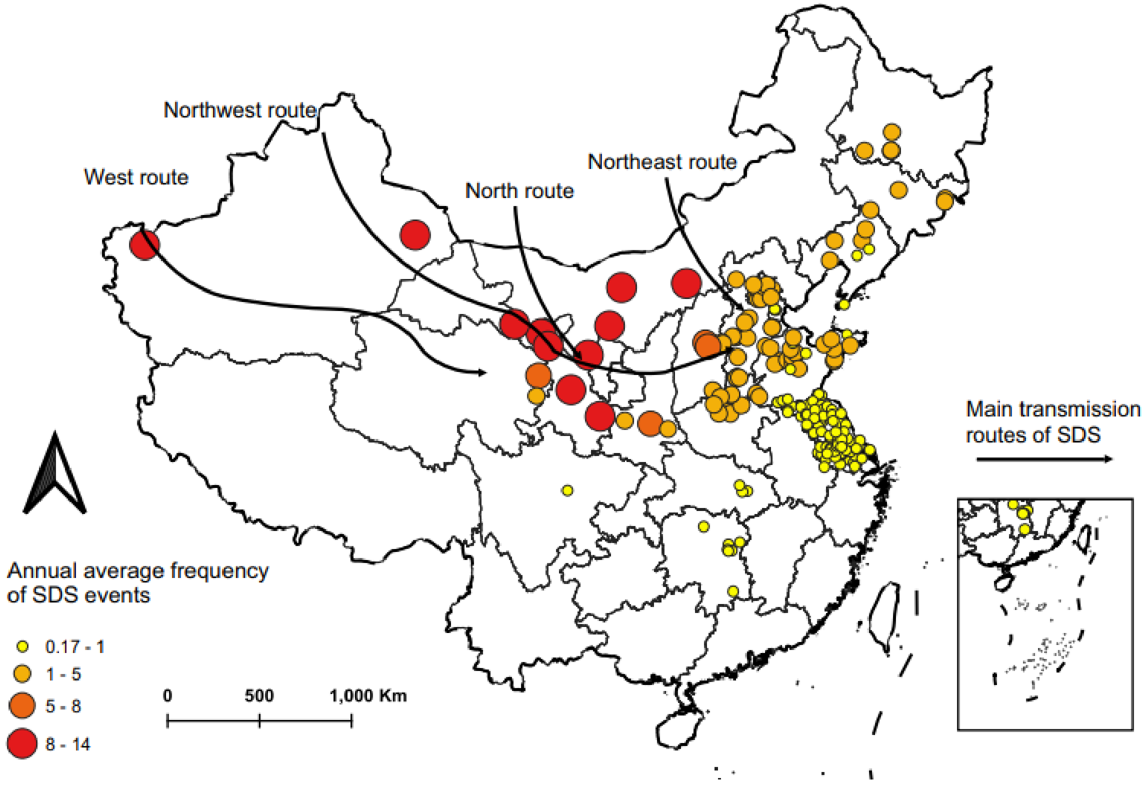


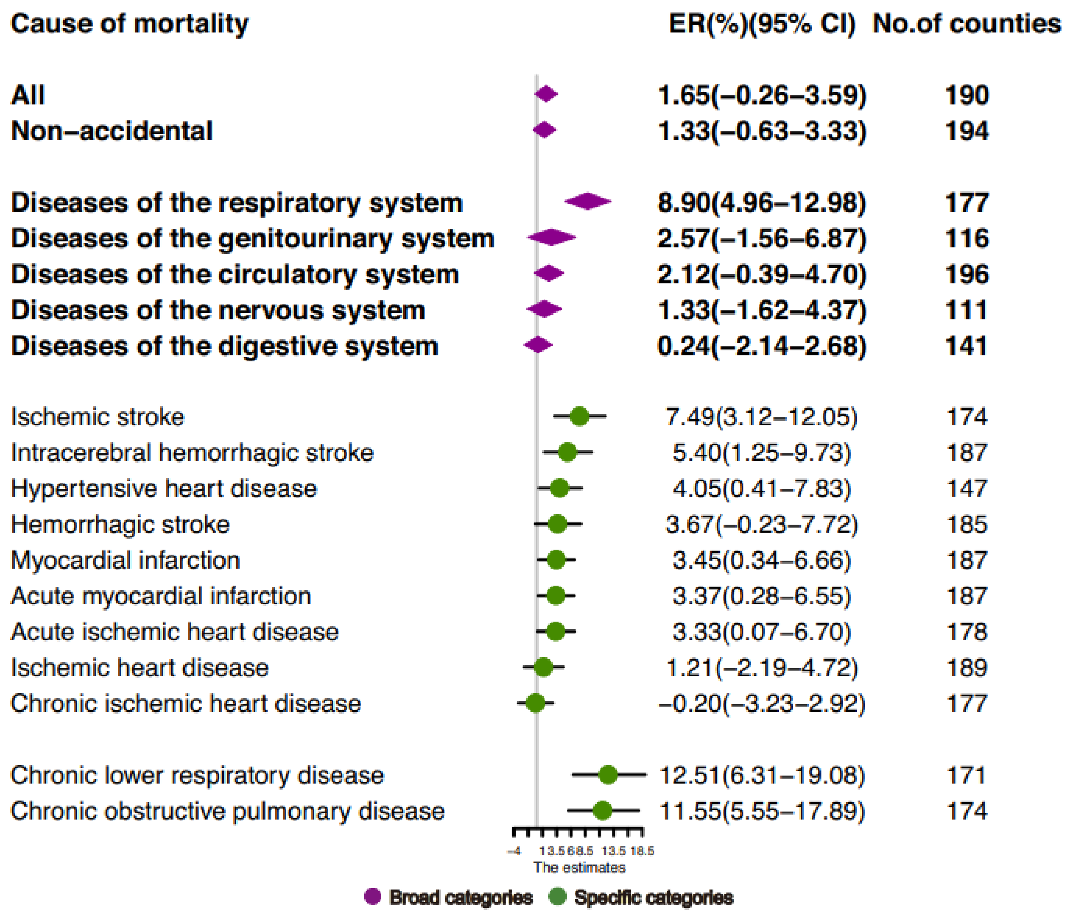
Lag 0

Other consequences of climate change

Zhang C, Nat Commun. 2023 Oct 27;14(1):6867

Sand and dust storms

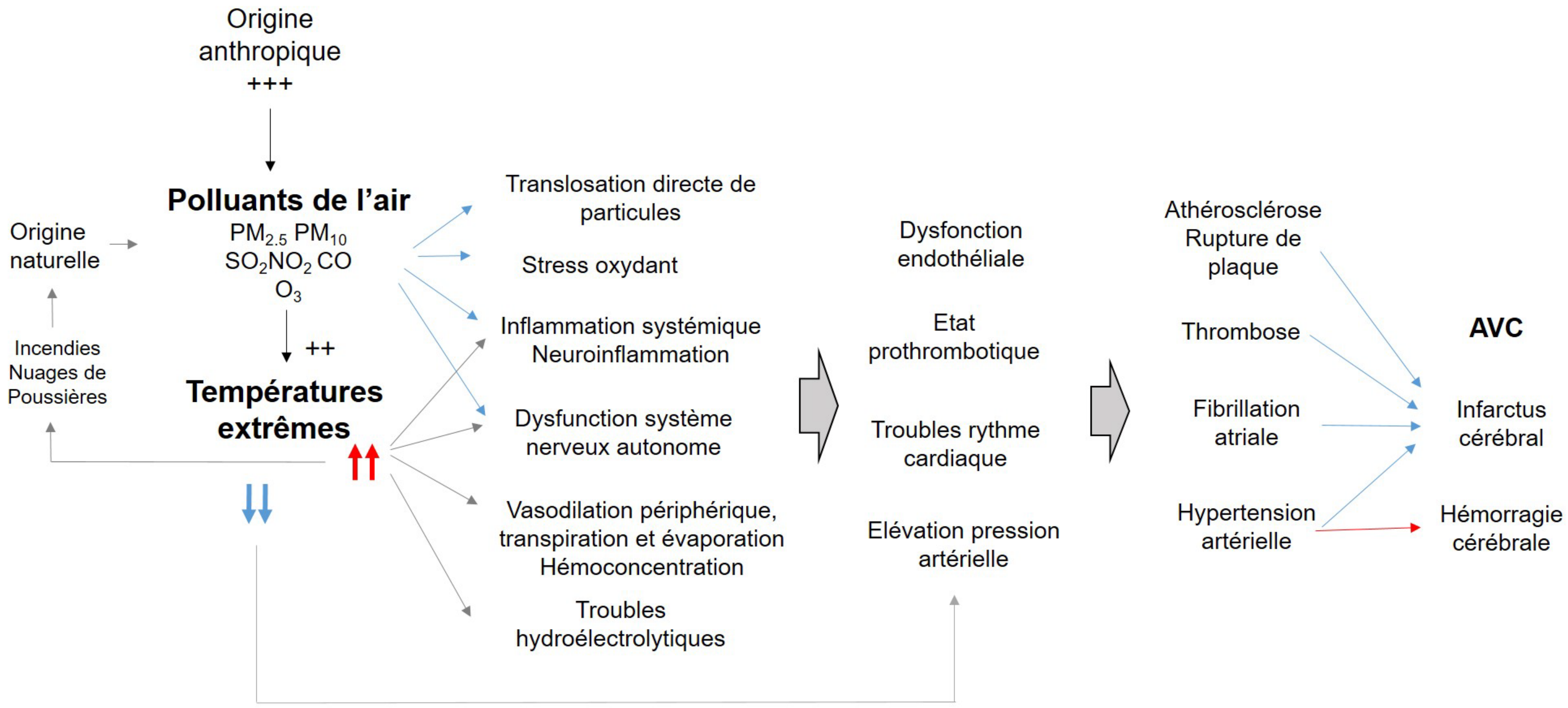




Mortality risk associated with sand and dust storms events at lag0 day

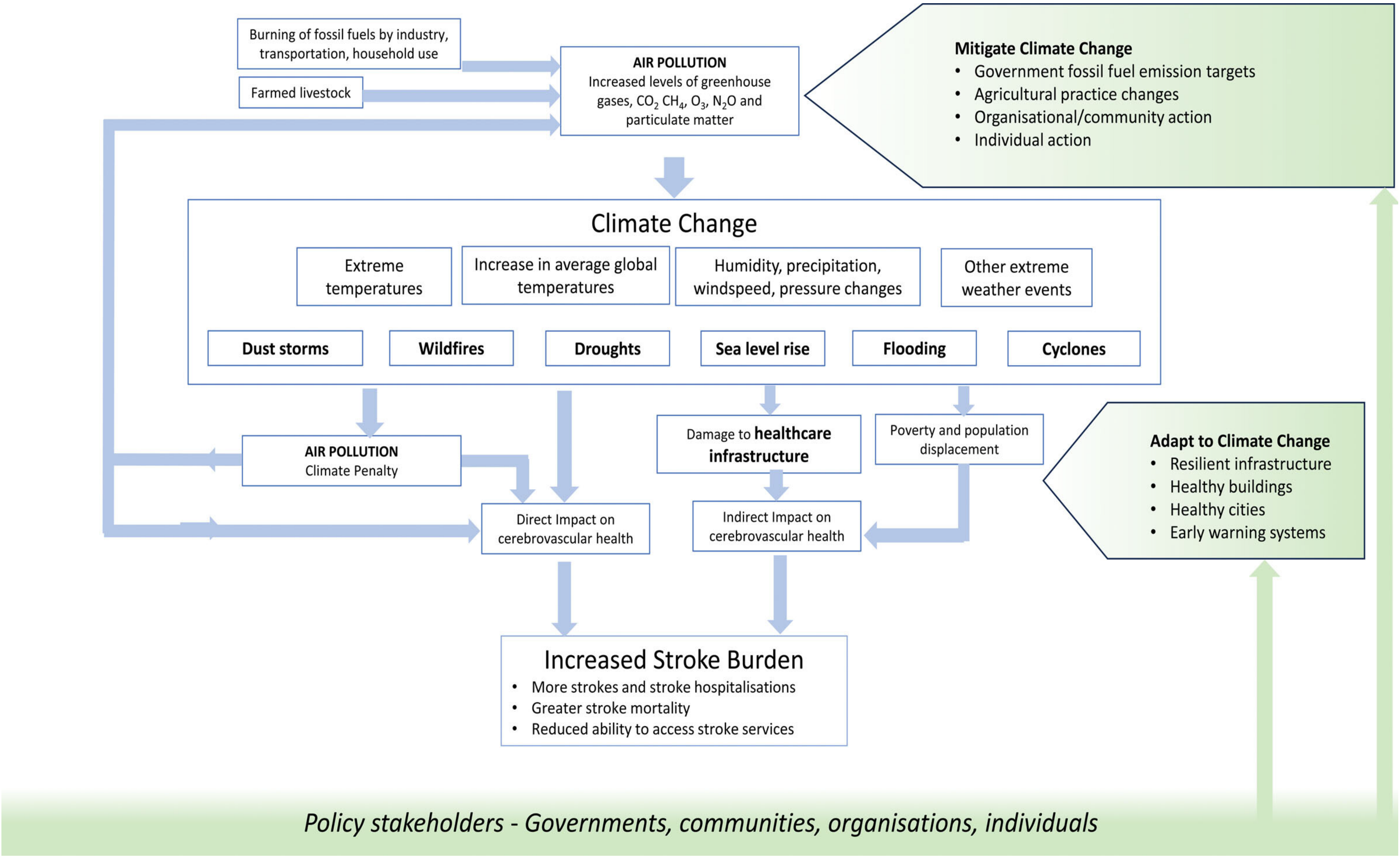
Pathophysiological approach

Béjot Y, Lettre du Neurologue 2025;3.



Climate change and stroke - summary

Ranta A, Stroke. 2024;55:1118-1128



Green space and stroke

Whyte M, J Neurol Sci. 2024;457:122870

Journal of the Neurological Sciences 457 (2024) 122870

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journal homepage: www.elsevier.com/locate/jns

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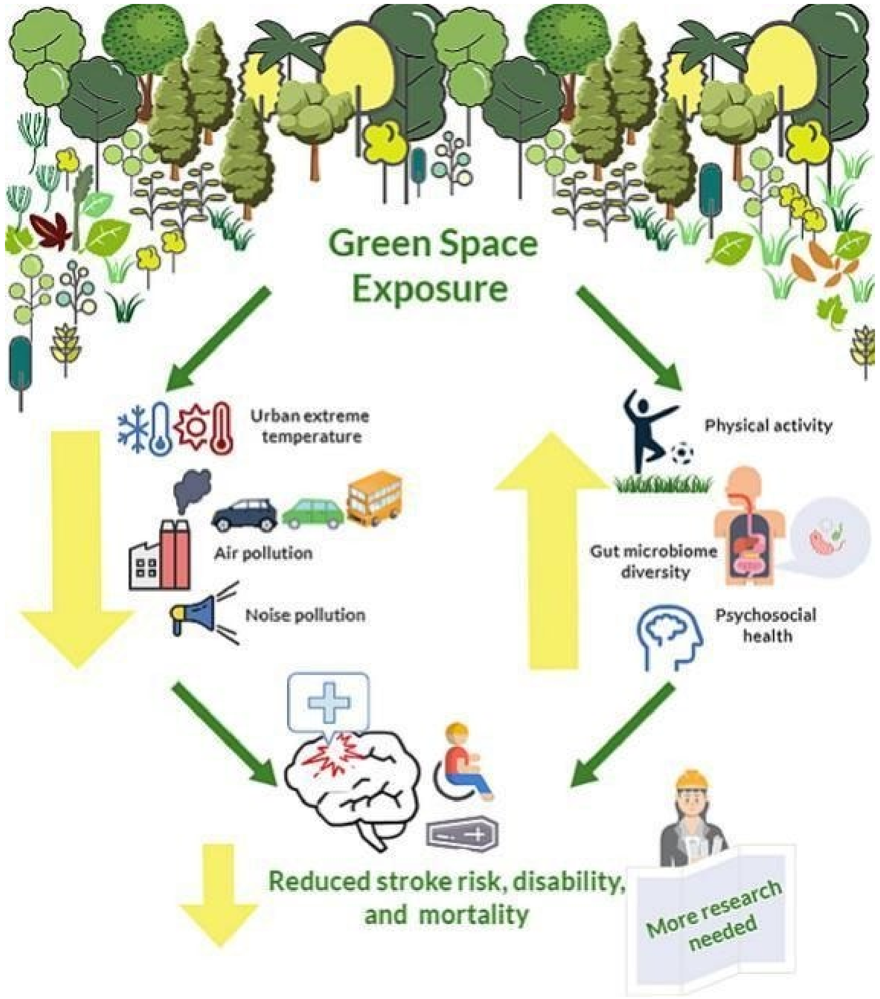
Green space and stroke: A scoping review of the evidence

Mina Whyte[a], Jeroen Douwes[b], Annemarei Ranta[a,*]

[a] Department of Medicine, University of Otago Wellington, PO Box 7343, Wellington 6242, New Zealand
[b] Research Centre for Hauora and Health, Massey University, Wellington, New Zealand

Protective association between green space exposure and:

- Stroke risk
- Stroke-related death
- Stroke-related disability

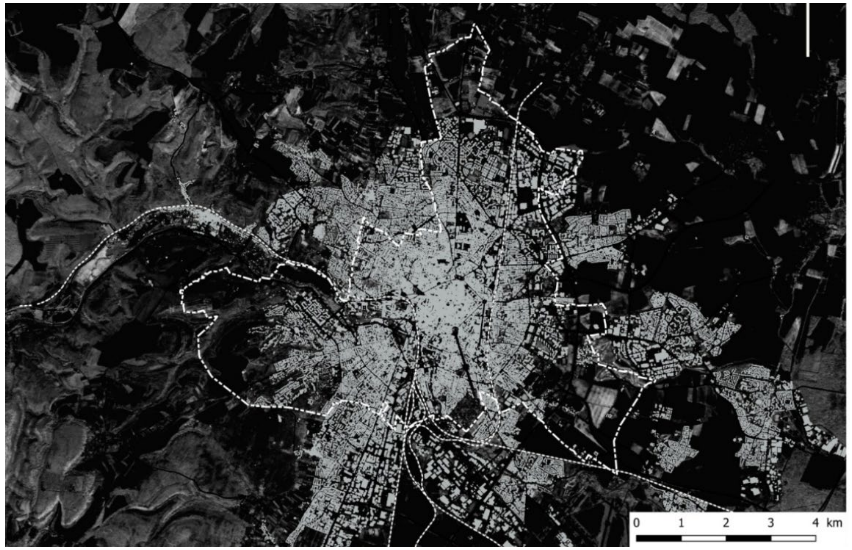


Urbanization and stroke

Anxionnat R, in revision

Green space and stroke

Dijon Stroke Registry (2005-2008)
First-ever ischemic stroke (n=360)
One-year recurrence / death



	Death after a first ischaemic stroke Hazard ratio [95% confidence interval] of green space variables			Recurrence after a first ischaemic stroke Hazard ratio [95% confidence interval] of green space variables		
	Model A-1 Crude Event: death (n = 15)	**Model A-2** Model A-1 + sex, age, mRS score, FDEP	**Model A-3** Model A-2 + previous 30 days PM_{10} concentrations	**Model B-1** Crude Event: recurrence (n = 17)	**Model B-2** Model B-1 + sex, age, mRS score, FDEP	**Model B-3** Model B-2 + previous 30 days PM_{10} concentrations
Public greenness proximity						
Nearest public green space by city network [a]	1.04 [0.80, 1.36]	1.17 [0.90, 1.51]	1.17 [0.89, 1.52]	**1.23 [1.02, 1.50] ***	**1.29 [1.07, 1.56] ****	**1.30 [1.07, 1.58] ****
Greenness density						
Area of green space within 100 metres of residence [b]	1.08 [0.96, 1.23]	1.09 [0.96, 1.25]	1.07 [0.93, 1.22]	**0.73 [0.54, 0.97] ***	**0.72 [0.54, 0.97] ***	**0.71 [0.53, 0.96] ***
Area of green space within 400 metres of residence [c]	1.06 [0.97, 1.16]	1.10 [0.98, 1.22]	1.06 [0.95, 1.19]	**0.80 [0.66, 0.98] ***	**0.77 [0.61, 0.97] ***	**0.76 [0.60, 0.96] ***

[a] Expressed for an increase of 100 metres
[b] Expressed for an increase of 1,000 m²
[c] Expressed for an increase of 10,000 m²
FDEP: French deprivation index, mRS: modified Rankin scale
Values in bold mean that they are statistically significant
* $P < 0.05$ ** $P < 0.01$

By age groups, HR [95% CI] of green space variables on composite event risk after a first ischaemic stroke
Event = death and/or recurrence
Models adjusted for sex, mRS score, FDEP, previous 30 days PM_{10} concentrations

	≤ 64 years (n event = 4)	65 – 79 years (n event = 9)	≥ 80 years (n event = 17)
Public greenness proximity			
Nearest public green space by city network [a]	1.12 [0.66, 1.88]	**1.37 [1.10, 1.71] ****	1.18 [0.92, 1.50]
Greenness density			
Area of green space within 100 metres of residence [b]	1.16 [0.92, 1.48]	0.92 [0.70, 1.21]	0.92 [0.77, 1.09]
Area of green space within 400 metres of residence [c]	1.11 [0.95, 1.31]	0.98 [0.80, 1.19]	0.87 [0.73, 1.04]

DIJON STROKE REGISTRY
DiSCo DIJON STROKE COHORT

Soil and water pollution, and stroke

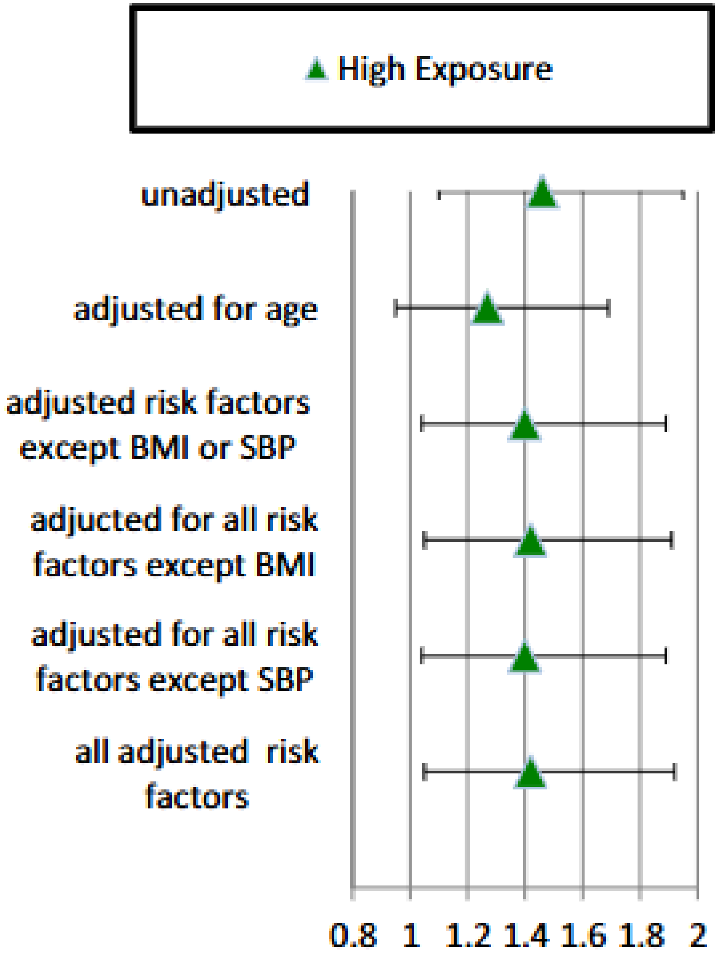
Pesticides

Berg ZK, J Am Heart Assoc.2019;8:e012569

- 7557 Japanese-American men from the Kuakini Honolulu Heart Program
- Exposure estimation: Occupational Safety Health Administration exposure scale
- 10-year follow-up

Exposure Level	Total N	Incident CVD	Unadjusted Rates	Age-Adjusted Rates
Incidence rates of CVD for the first 10-y follow-up period				
No exposure	7016	550	8.34	8.48
Low-moderate exposure	110	5	4.74	4.28
High exposure	451	51	12.2	10.74

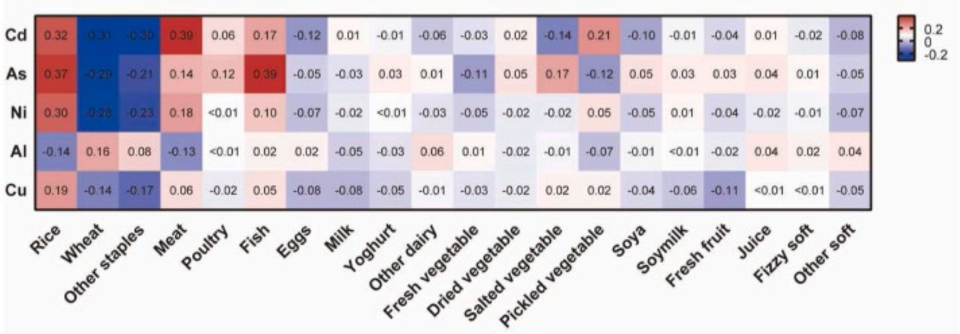
Coronary heart disease and stroke



Soil and water pollution, and stroke

Metals exposure

Xu L, Environ Res. 2022;205:112535



19,380 adults in China during 2013–2014

Prevalence ratios of stroke by quintiles of urinary creatinine-corrected element levels

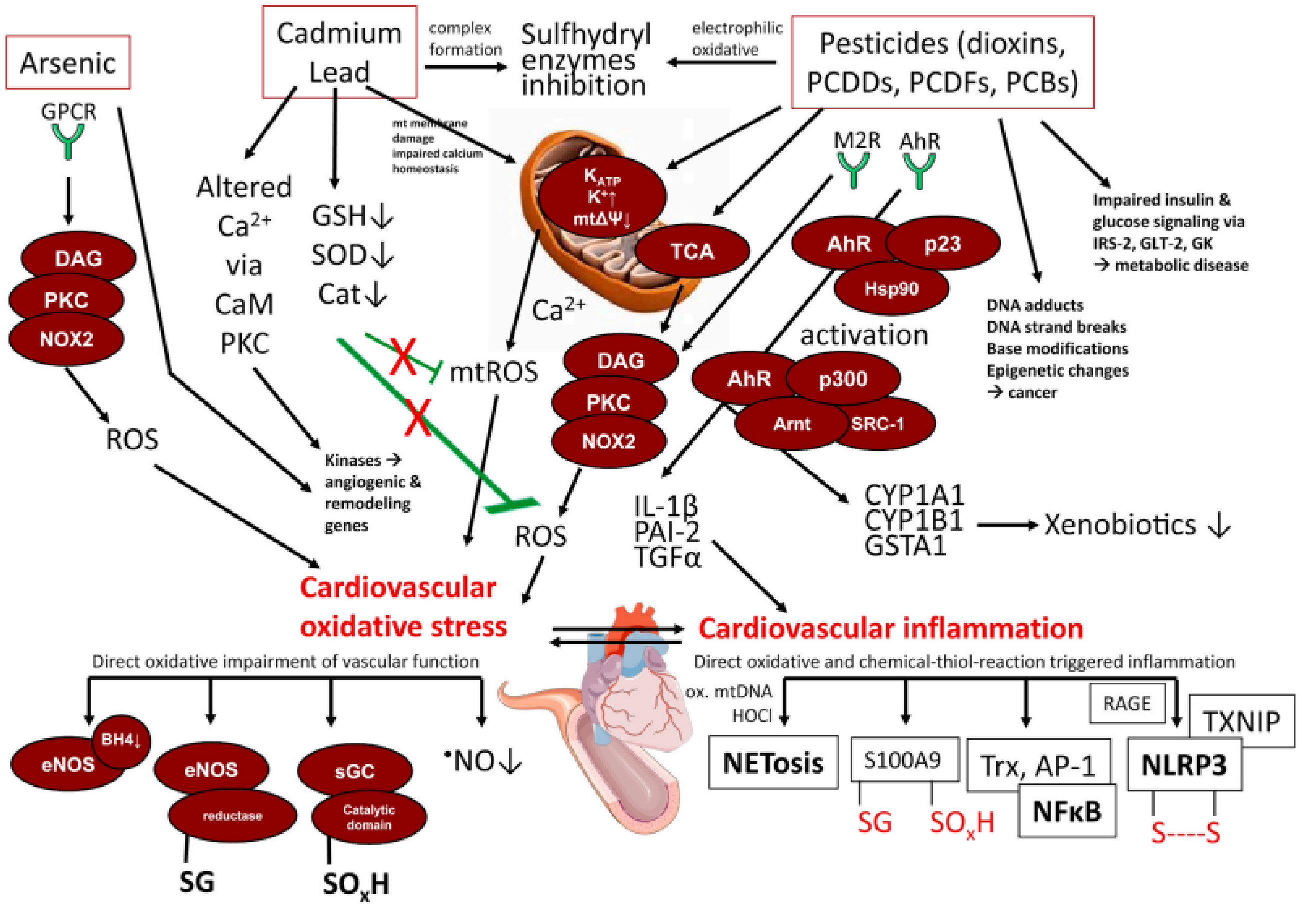
		Q1	Q2	Q3	Q4	Q5	*P*-trend [c]	Per SD
Cd	**N case/N no case**	261/3582	294/3548	273/3569	281/3561	191/3652		
	Model 1 [a]	Ref	1.23 (1.05–1.43)	1.26 (1.06–1.49)	1.47 (1.22–1.79)	1.35 (1.05–1.72)	0.003	1.14 (1.05–1.23)
	Model 2 [b]	Ref	1.22 (1.04–1.43)	1.26 (1.06–1.49)	1.46 (1.21–1.77)	1.34 (1.05–1.71)	0.003	1.13 (1.04–1.23)
As	**N case/N no case**	266/3577	239/3603	227/3615	239/3603	329/3514		
	Model 1 [a]	Ref	0.93 (0.79–1.11)	0.88 (0.73–1.06)	0.89 (0.73–1.08)	1.09 (0.90–1.32)	0.162	1.03 (0.96–1.10)
	Model 2 [b]	Ref	0.95 (0.80–1.12)	0.89 (0.74–1.08)	0.90 (0.74–1.10)	1.11 (0.92–1.35)	0.126	1.03 (0.97–1.10)
Ni	**N case/N no case**	251/3592	277/3565	258/3584	250/3592	264/3579		
	Model 1 [a]	Ref	1.07 (0.91–1.26)	0.99 (0.83–1.18)	0.98 (0.82–1.17)	1.10 (0.92–1.32)	0.528	1.04 (0.98–1.11)
	Model 2 [b]	Ref	1.07 (0.91–1.26)	0.99 (0.83–1.17)	0.98 (0.82–1.17)	1.09 (0.91–1.31)	0.587	1.04 (0.98–1.10)
Al	**N case/N no case**	209/3634	230/3612	265/3577	302/3540	294/3549		
	Model 1 [a]	Ref	0.97 (0.81–1.15)	1.03 (0.86–1.22)	1.11 (0.94–1.32)	1.03 (0.87–1.23)	0.360	1.05 (0.99–1.11)
	Model 2 [b]	Ref	0.97 (0.81–1.15)	1.03 (0.87–1.22)	1.11 (0.94–1.31)	1.03 (0.86–1.23)	0.381	1.05 (0.99–1.11)
Cu	**N case/N no case**	225/3618	263/3579	247/3595	260/3582	305/3538		
	Model 1 [a]	Ref	1.19 (1.01–1.41)	1.15 (0.97–1.37)	1.18 (0.99–1.40)	1.29 (1.09–1.53)	0.007	1.04 (0.98–1.10)
	Model 2 [b]	Ref	1.20 (1.01–1.41)	1.15 (0.97–1.37)	1.18 (0.99–1.39)	1.29 (1.09–1.53)	0.007	1.04 (0.98–1.10)

[a] Model 1: adjusted for gender, age, region, education, household income, family history of CVDs, smoking, alcohol, physical activity, menopausal status, and BMI.
[b] Model 2: model 1 plus diet categories.
[c] *P*-trend was obtained by assigning a median value to each quintile of urinary element and treating it as a continuous variable in the regression model.

cadmium (Cd)
arsenic (As)
nickel (Ni)
aluminum (Al)
copper (Cu)

Overview of pathophysiological mechanisms
metals and pesticides

Münzel T, Atherosclerosis. 2025:403:119160



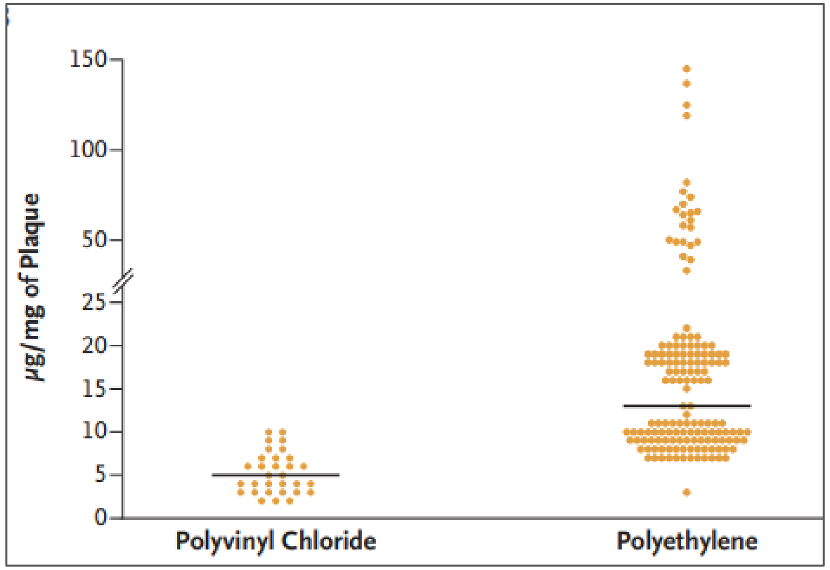
Micro- and nano-plastics

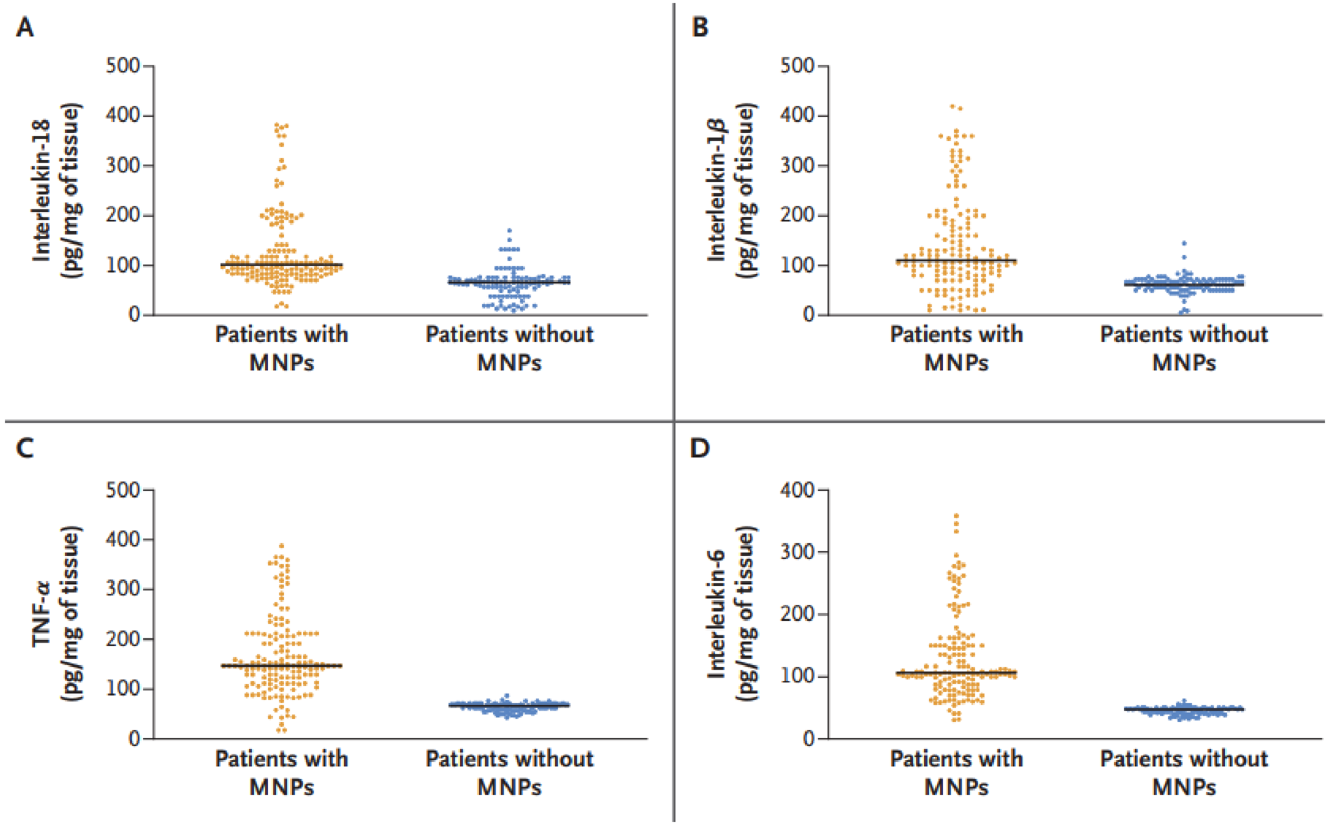
Marfella R, N Engl J Med 2024;390:900-10

257 patients with endarterectomy for asymptomatic carotid artery stenosis (>70%)
Mean (±SD) follow-up of 33.7±6.9 months

150 Had evidence of MNPs in carotid artery plaque

107 Did not have evidence of MNPs in carotid artery plaque

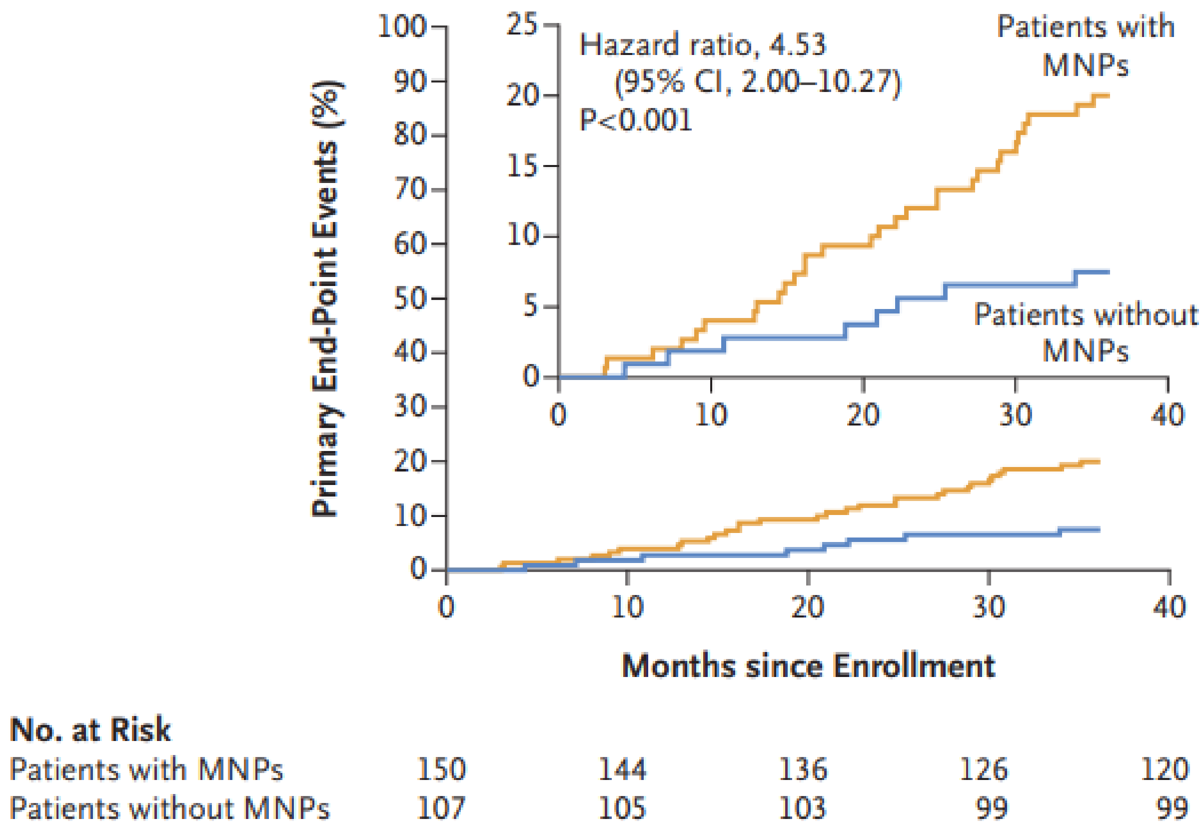




Micro- and nano-plastics

Marfella R, N Engl J Med 2024;390:900-10

Associations between the Presence of MNPs and Cardiovascular Events



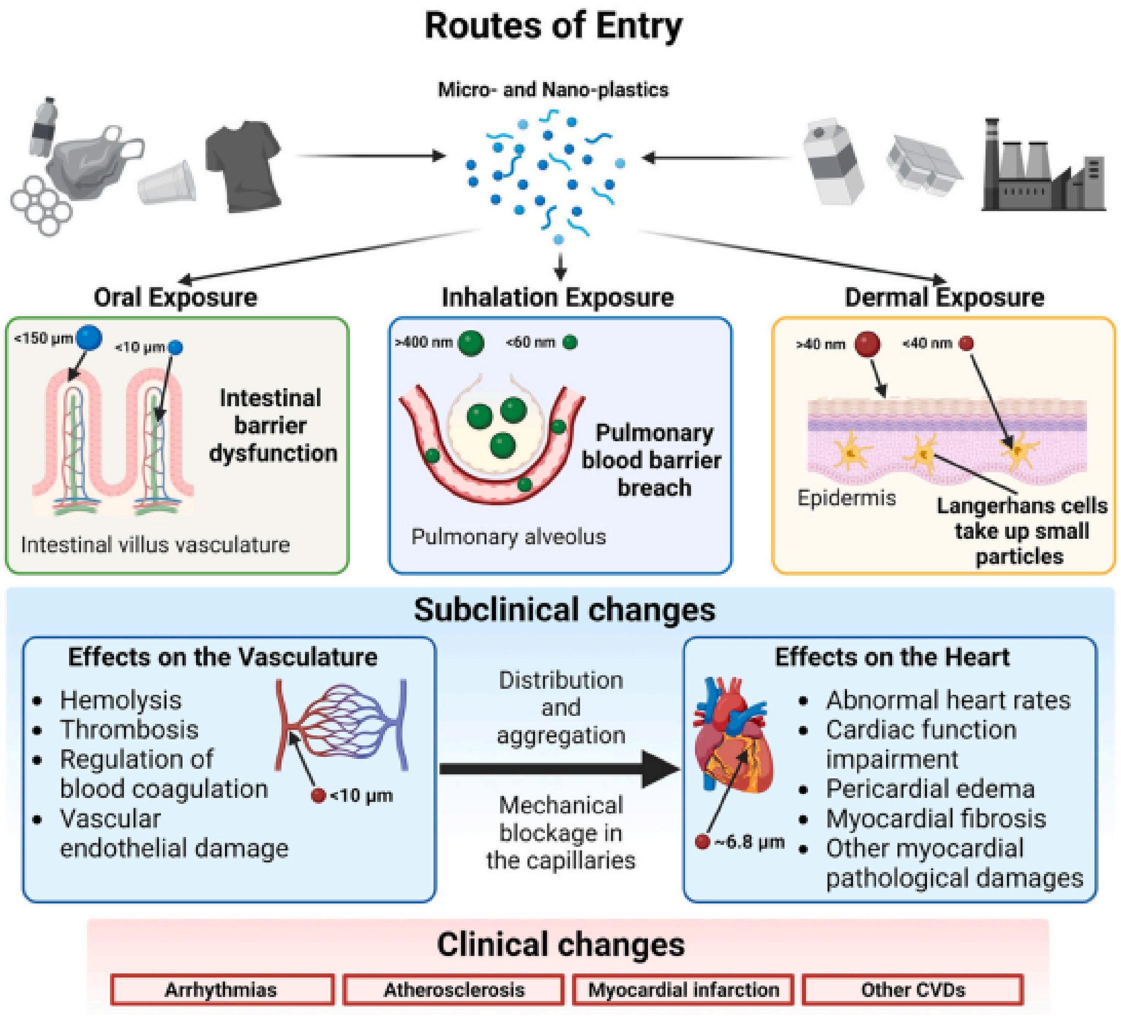
	Patients without micronanoplastics (n= 107)	Patients with micronanoplastics (n= 150)
Stroke — no.	5	14
Myocardial infarction — no.	2	10
All cause death — no.	1	6

nonfatal myocardial infarction, nonfatal stroke, or death from any cause

Soil and water pollution, and stroke

Micro- and nano-plastics

Münzel T, Atherosclerosis. 2025:403:119160



Conclusion

Criteria for causality in epidemiological research

1. **Strength of the association.** ✓
The stronger the association between a risk factor and outcome, the more likely the relationship is to be causal

2. **Consistency of findings** ✓
Have the same findings must be observed among different populations, in different study designs and different times?

3. **Specificity of the association** ±
There must be a one to one relationship between cause and outcome

4. **Temporal sequence of association** ✓
Exposure must precede outcome

5. **Biological gradient** ✓
Change in disease rates should follow from corresponding changes in exposure (dose-response)

6. **Biological plausibility** ✓
Presence of a potential biological mechanism

7. **Coherence** ✓
Does the relationship agree with the current knowledge of the natural history/biology of the disease?

8. **Experiment** ?
Does the removal of the exposure alter the frequency of the outcome?

Invité d’honneur : Société Cérébrovasculaire Suisse

Centre Hospitalier Universitaire
Dijon Bourgogne

Contact: yannick.bejot@chu-dijon.fr

DIJON STROKE REGISTRY

DiSCo
DIJON STROKE COHORT

PEC2
ÉQUIPE D'ACCUEIL - EA 7460
Physiopathologie & Épidémiologie Cérébro-Cardiovasculaires

UNIVERSITÉ BOURGOGNE EUROPE