Supplementary material

A systematic analysis of mutual effects of transportation noise and air pollution exposure on myocardial infarction mortality: a nationwide cohort study in Switzerland

Harris Héritier[1,2*], Danielle Vienneau[1,2*], Maria Foraster[1,2], Ikenna C. Eze[1,2], Emmanuel Schaffner[1,2] Laurie Thiesse[3], Franziska Rudzik[3], Kees de Hoogh[1,2], Manuel Habermacher[4], Micha Köpfli[4], Reto Pieren[5], Mark Brink[6], Christian Cajochen[3], Jean Marc Wunderli[5], Nicole Probst-Hensch[1,2], Martin Röösli [1,2] for the SNC study group

[1] Swiss Tropical and Public Health Institute, Basel, Switzerland

[2] University of Basel, Basel, Switzerland

[3] Centre for Chronobiology, Psychiatric Hospital of the University of Basel, Basel, Switzerland

[4] N-sphere AG, Zürich, Switzerland

[5] Empa, Laboratory for Acoustics/Noise control, Swiss Federal Laboratories for Materials Science and Technology, Dubendorf, Switzerland.

[6] Federal Office for the Environment, Bern, Switzerland

* both authors contributed equally.

Correspondence:

Martin Röösli

Swiss Tropical and Public Health Institute

Socinstrasse 57

P.O. Box

CH-4002 Basel

E-Mail martin.roosli@unibas.ch

Tel. +41 (0)61 284 83 83

Fax +41 (0)61 284 85 01

Predictors and modeling strategy of the NO2 model

The following spatial predictors to were used to construct a NO2 model for the whole country:

- Building footprints of the year 2008 derived from Vector25, the digital landscape model of Switzerland.[1]
- Population density data at a 100×100 m grid were available for 2011 from the Bundesamt für Statistik (BfS) for Switzerland,[2] supplemented with a 100×100 m resolution European population grid for 2000 for the border areas.[3]
- CORINE Land Cover from the European Environment Agency for the year 2006. This was reclassified into 6 classes (Industry, water bodies, urban, farming, natural, and rocky natural).
- Road network and modelled traffic intensity data from 2008 from Vector 25[1] with resolution 1:25,000 were available from Swisstopo.

The above predictors were calculated for various buffer sizes (i.e. 25, 50, 75, 100, 150, 250, 500, 750, 1000m) around the place of residence. The following predictors refer to the coordinate of the home address:

- Elevation at residential was extracted from a 25m digital height model of Switzerland (DHM25) from the Federal Office for Topography.[4]
- The Topex indicator,[5] which reflects 'topographic exposure,' was computed by subtracting the altitude averaged over the 1000m buffer by the altitude at the point coordinate.
- NO_2 concentration at the residential coordinates from the PolluMap dispersion model for Switzerland at a 200×200 m resolution, for the individual years 2000-2005.[6]

Predictor selection for the models was conducted by elastic net regularization using the package glmnet in R,[7] by selecting the minimum lambda value following a 10-fold cross-validation. The NO_2 concentrations for each year from 2000 to 2008 were predicted and we extracted the residuals which where fitted based on an exponential variogram. The resulting fitted variogram was subsequently kriged yielding a smoothed layer that corrected the over- and under-predicted values. These predictions were independently validated using data from the NABEL network (652 data points collected from 2000 to 2008 at 137 locations). The prediction for the SNC at residential address was performed for each year, from 2000 to 2008, in two stages. We first predicted the annual NO_2 concentrations based on the elastic net models and in the second stage, we extracted the residuals from the annual kriged surface. First stage prediction and second stage residuals were then added to yield the final prediction.

References

1. *VECTOR25–Das digitale Landschaftsmodell der Schweiz*. Informationsbroschüre des Bundesamts FÜR Landestopographie der Schweiz: Wabern, 2000.
2. Basner M, Muller U, Elmenhorst EM. Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. *Sleep* 2011; **34**:11-23.
3. Gallego FJ. A population density grid of the European Union. *Popul Environ* 2010; **31**:460-473.
4. Digital height model of Switzerland. In Swisstopo, Ed. Swisstopo: Wabern, 2005.
5. Beelen R, Hoek G, Pebesma E, Vienneau D, de Hoogh K, Briggs DJ. Mapping of background air pollution at a fine spatial scale across the European Union. *Science of the Total Environment* 2009; **407**:1852-1867.
6. FOEN. NO2 ambient concentrations in Switzerland, Modelling results for 2005, 2010, 2015. In Federal Office for the Environment: Berne, 2011.
7. Friedman J, Hastie T, Tibshirani R. Regularization Paths for Generalized Linear Models via Coordinate Descent. *Journal of Statistical Software* 2010; **33**:1-22.

Table S1: Predictors and coefficients of the NO_2 model for years 2000 to 2008

Predictors	2000	2001	2002	2003	2004	2005	2006	2007	2008
(Intercept)	28.70	26.79	26.48	26.17	24.71	25.58	26.62	24.88	25.18
Pollumap 2000	3.20	-	-	-	-	-	-	-	-
Pollumap 2001	-	2.82	-	-	-	-	-	-	-
Pollumap 2002	-	-	4.70	-	-	-	-	-	-
Pollumap 2003	-	-	-	4.24	-	-	-	-	-
Pollumap 2004	-	-	-	-	2.66	-	-	-	-
Pollumap 2005	-	-	-	-	-	3.45	3.12	3.02	2.67
Elevation	-1.68	-1.07	-0.84	-0.94	-0.16	-0.72	-0.13	-0.01	
Topex	-	-	0.43	0.54	-	-	-	0.17	0.13
Industry 25m	-	-	-	-	0.62	-	-	-	0.06
Industry 50m	0.44	0.36	0.34	0.37	0.03	-	-	-	0.00
Industry 100m	-	-	-	-	-	-	0.16	0.11	0.23
Industry 150m	-	0.41	0.39	-	-	0.12	-	0.15	-
Industry 250m	-	-	-	-	-	0.16	0.02	-	-
Industry 750m	-	-	-	-0.32	-0.18	-	-	-	-
Industry 1000m	0.10	-	-	-	-	0.01	-	-	0.11
Water 25m	-	-	-	0.00	-	0.00	-	-	-
Water 50m	0.03	-	-	-	-	0.17	-	-	-
Water 75m	-	-	0.13	0.18	0.20	-	-	0.12	-
Water 100m	-	-0.17	-0.16	-0.23	-	-	-	-	-
Water 250m	-	-	0.05	0.01	-	-	-	-	0.23
Water 1000m	-0.73	-0.03		-0.34	-0.21	-0.79	-	-0.19	-0.47
Urban 100m	-	-	-	-	-0.12	-0.45	-	-	-
Urban 150m	-0.13	-	-	-0.66	-0.05	-	-	-0.05	-
Urban 1000m	0.28	0.42	0.51	0.23	0.79	0.50	-	-	0.06
Nature 100m	-	-	-	0.27	0.04	-	-	-	-
Nature 150m	0.38	-	-	0.02	0.15	-	-	-	-
Nature 500m	-	-0.83	-0.39	-1.04	-0.51	-0.58	-0.42	-0.47	-0.50
Nature 750m	-1.48	-0.43	-	-	-	-0.04	-	-	-
Agriculture 500m	-	-	0.29	0.35	-	-	-	-	-
Agriculture 1000m	-	-	-0.54	-1.22	-	-	-	-	-
Population 25m	-0.02	-	-0.04	-	-	0.06	-	-	-
Population 50m	-0.09	-	-0.15	-	-	-	-	-	-
Population 75m	-	-	0.09	-	-	-	-	-	-
Population 100m	0.42	0.13	0.35	0.22		0.43	0.14	0.14	0.16
Population 150m	-	-	-	-	0.21	-	-	-	-
Population 250m		0.25		0.09	0.31	0.10	0.08	0.12	0.19
Population 500m	-	-	0.22	-	-	-	-	-	-
Population 1000m	0.64	0.10	0.00	-	-	-	-	-	-

Table S1 continued

Predictors	2000	2001	2002	2003	2004	2005	2006	2007	2008
Class1 road 25m	1.51	1.57	1.92	2.10	1.84	2.20	2.21	2.32	2.42
Class1 road 50m	-	-	0.22	-	-	-	-	-	-
Class1 road 75m	1.46	1.21	0.45	0.40	0.07		0.48	0.97	0.90
Class1 road 100m	-	0.20	0.10	0.43	1.11	0.93	0.14	0.07	0.20
Class1 road 150m	-	-	-	0.12	0.10	0.01	-	-	-
Class1 road 250m	-	-	-	0.20	-	-	-	-	-
Class1 road 500m	-	0.20	-	-	-	-	-	-	-
Class1 road 750m	-	-	-	-	-	-	0.03	-	-
Class1 road 1000m	-	-	0.03	0.14	0.12	-	0.07	-	-
Class2 road 25m	0.27	0.54	0.45	0.53	0.39	0.16	-	0.09	0.13
Class2 road 50m	0.52	0.21	0.28	0.28	0.28	0.73	0.37	0.72	0.65
Class2 road 75m	0.05	-	0.28	0.09	-	-	-	-	-
Class2 road 100m	-	-	-	0.30	0.27	-	0.02	-	-
Class2 road 150m	-	-	-	-	-	-	-	-	0.00
Class2 road 500m	-0.48	-0.25	-0.22	-	-	-	-	-	-
Class2 road 750m	-	-	-	-	-	-	-	-	-0.04
Class2 road 1000m	-	-	-	0.28	-	-	-	-	-
Class3 road 25m	-	0.16	0.33	-	0.12	-	-	-	-
Class3 road 50m	0.24	-	-	-	-	-0.17	-	-	-
Class3 road 75m	-	-	-	-	-	-	-0.06	-0.12	-
Class3 road 100m	-	-	-	-	0.02	-	-	-	-
Class3 road 150m	-0.29	-	-0.02	-0.03	-	-	-	-	-
Class3 road 250m	-	-0.30	-0.06	-	0.00	-	-0.03	-0.25	-0.34
Class3 road 500m	-	-	-	-	-	-	-	-	-0.17
Class3 road 750m	-	-	-	-	0.01	-0.24	-	-	-
Class3 road 1000m	-	-	0.47	0.63	-	-0.14	-	-	-
Highway 25m	0.13	0.42	0.72	0.24	0.16	0.33	0.78	0.71	0.97
Highway 50m	0.19	-	-	0.04	-	0.50	0.36	-	0.20
Highway 75m	1.33	1.04	0.71	0.47	0.80	-	0.15	0.80	0.33
Highway 150m	-	-	-	0.43	0.75	0.64	0.34	-	-
Highway 250m	-	1.03	0.72	0.84	0.75	0.15	-	-	-
Highway 500m	0.32	0.06	-	-	0.58	-	0.11	0.28	0.50
Highway 750m	-	0.18	0.26	0.29	-	0.39	0.62	0.40	-
Highway 1000m	-	-	0.38	1.22	0.65	0.23	0.08	0.30	0.12

Table S1 continued

Predictors	2000	2001	2002	2003	2004	2005	2006	2007	2008
Building density 25m	0.34	-	0.27	0.22	-	0.14	-	0.00	-
Building density 50m	0.27	0.36	0.31	0.24	0.34	0.65	0.30	0.49	0.67
Building density 75m	0.86	0.43	-	0.15	0.16	0.01	0.12	0.33	-
Building density 100m	-	-	-	-	-	-	0.35	0.10	-
Building density 150m	0.40	0.59	0.85	0.95	1.13	1.23	0.76	0.77	1.14
Building density 250m	-	-	-	-	-	-	-	-	0.09
Building density 750m	-	-	-	-	-	-	0.31	-	-
Building density 1000m	-	0.00		0.46	0.89	0.80	1.04	1.22	0.71
N trucks 25m	1.37	1.09	0.56	1.05	1.04	0.92	0.03	0.17	0.12
N trucks 50m	-	-	-	-	-	0.15	0.20	0.26	0.32
N trucks 75m	-	-	-	-	-	-	0.06	-	0.00
N trucks 150m	-	-	-	-	-	-	-	-	0.13
N trucks 250m	0.19	0.14	-	0.09	0.08	0.19	-	0.37	0.28
N trucks 750m	-	-	-	-0.18	-	-	-	-	0.13
N trucks 1000m	-	-	-0.06	-0.07	-	-	-	-	-
N motorbikes 25m	-0.29	-	-	-0.38	-0.05	-0.47	-	-	-
N motorbikes 50m	0.09	0.14	0.35	0.39	0.29	-	-	0.16	-
N motorbikes 75m	-0.15	-	-	-	-	-0.14	-	-	-
N motorbikes 100m	-	-	-	-	-	-	0.61	0.02	0.45
N motorbikes 150m	0.30	-	-	0.27	-	0.25	0.06	-	-
N motorbikes 250m	-	-	-	0.05	-	-	-	-	-
N motorbikes 500m	0.23	0.01	-	-	-	-	-	-	-
N motorbikes 1000m	-	0.10	-0.07	-	-	0.00	-	-	0.15
N cars 25m	-	-	-	-	-	-	0.02	-	0.19
N cars 50m	-	-	-	-	-	0.23	0.19	-	-
N cars 75m	-	-	-	-0.44	-0.17	-	-	-	-
N cars 1000m	-	-	-0.47	-0.17	-	-	-	-	-

Table S2: NO_2 model building and validation statistics by year

Year	Cantonal passive sampling data				NABEL data		
	N sites training	Elastic net cross-validation R^2	Elastic net + kriging prediction R^2	Elastic net + kriging SEE	N sites for validation	Validation R^2	RMSE
2000	980	0.60	0.89	3.53	78	0.73	5.83
2001	886	0.61	0.89	3.31	81	0.78	4.79
2002	975	0.69	0.90	3.13	86	0.82	4.20
2003	1308	0.70	0.87	3.88	93	0.70	6.06
2004	947	0.65	0.87	3.46	99	0.75	5.15
2005	1169	0.68	0.88	3.44	98	0.75	5.32
2006	1097	0.65	0.85	3.72	114	0.71	5.65
2007	1145	0.64	0.84	3.75	135	0.72	5.64
2008	1194	0.63	0.85	3.67	146	0.74	5.39

Predictors and modeling strategy of the $PM_{2.5}$ model

The development of the PM2.5 model is described in detail in de Hoogh et al, 2017.[8] Global and local land use predictors for the PM2.5 model included:

- $PM_{2.5}$ emissions from agriculture, households, industry, traffic and wood smoke for the years 2005 and 2010 obtained from MeteoTest at a 200×200 m grid.
- Distance to nearest main road, computed from the VECTOR25 road network.
- Elevation from the DHM25 at a 200×200 m grid.
- Land use from the European CORINE land cover at 100×100 m resolution.
- Meteorological data including daily modelled planetary boundary layer data, daily temperature, wind speed, wind direction and precipitation at a ~10×10 km resolution from 1 January 2003 until 31 December 2013 from the European Centre for Medium-Range Weather Forecasts.
- Normalized Difference Vegetation Index in a 30×30 m raster for year 2014, mosaicked from scenes downloaded from the USGS EarthExplorer website (http://earthexplorer.usgs.gov).[9]

A 4-staged modelling approach[10] was adapted and further developed to calibrate the satellite data with measured $PM_{2.5}$ concentrations. The measured $PM_{2.5}$ dataset consisted of 10 daily measurement sites. To increase the number of measurement sites we applied the ratio between $PM_{2.5}$ and PM_{10} data (daily; Jan 2003 - April 2010 and four-daily; April 2010 – Dec 2013) from 10 co-located monitoring sites of the NABEL network to predict $PM_{2.5}$ concentrations at sites where only PM_{10} measurements were available, supplementing the monitoring dataset with an extra 89 measurement sites. At the 1km scale, mixed effect models (stage 1) were generated regressing $PM_{2.5}$ measurements against day-specific random intercepts, fixed and random AOD and boundary layer height slopes, and fixed effects for spatial covariates. These mixed effect models were then used to predict $PM_{2.5}$ in cells were AOD was available, but without a $PM_{2.5}$ measurement (stage 2). Next, a generalized additive mixed model with spatial smoothing was applied to generate grid cell predictions for those grid cells where AOD was missing (stage 3). To estimate 100m localized $PM_{2.5}$ predictions, the residuals from the stage 1 model at each monitoring site were regressed against the local spatial and temporal variables at each monitoring site (stage 4) using machine learning techniques. This resulted in a $PM_{2.5}$ model for each year for the period 2003-2008.

References

8. de Hoogh K, Héritier H, Stafoggia M, Künzli N, Kloog I. Modelling daily PM2. 5 concentrations at high spatio-temporal resolution across Switzerland. *Environmental Pollution* 2017.
9. Vienneau D, de Hoogh K, Faeh D, Kaufmann M, Wunderli JM, Röösli M, Group SNCS. More than clean air and tranquillity: Residential green is independently associated with decreasing mortality. *Environ Int* 2017; 108:176-184.
10. Kloog I, Chudnovsky AA, Just AC, Nordio F, Koutrakis P, Coull BA, Lyapustin A, Wang Y, Schwartz J. A new hybrid spatio-temporal model for estimating daily multi-year PM2.5 concentrations across northeastern USA using high resolution aerosol optical depth data. *Atmospheric Environment* 2014; 95:581-590.

Figure S1: Distribution of mean NO_2 (2000 to 2008) and mean $PM_{2.5}$ (2003 to 2008) exposure in the study population.

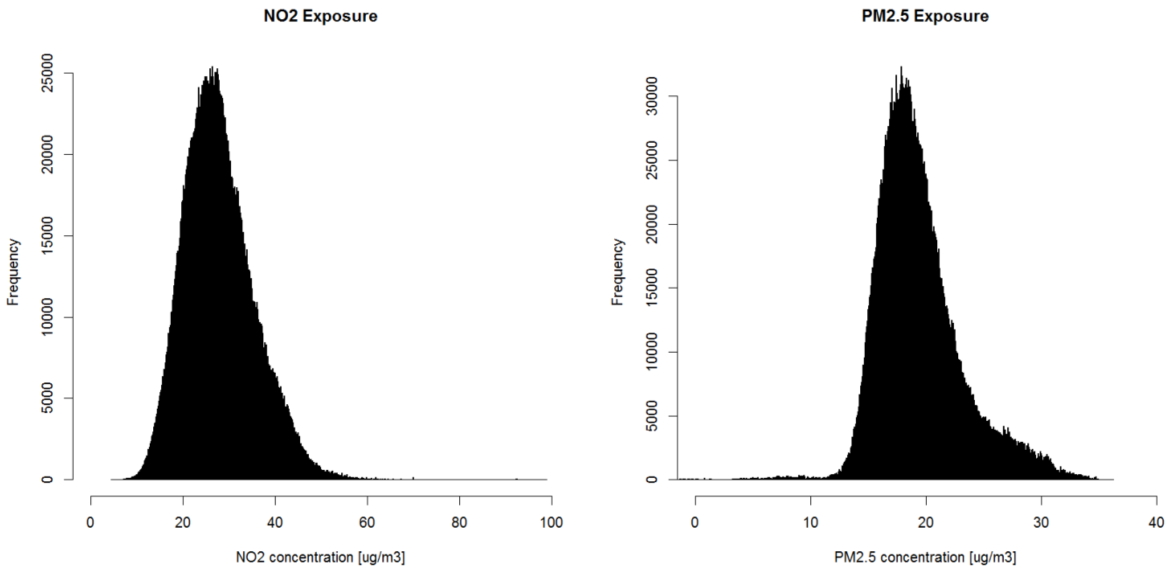

Table S3: linear HRs for associations between road, railway, and aircraft noise exposure and MI per 10 dB increase in Lden for models: crude, adjusted for sociodemographics but not air pollution (AP), adjusted for $PM_{2.5}$, adjusted for NO_2, and adjusted for $PM_{2.5}$ and NO_2

Noise source	Crude[1]	Adjusted (no AP) (95% CI)[2]	Adj for $PM_{2.5}$ (95% CI)[2]	Adj for NO_2 (95% CI)[2]	Adj for $PM_{2.5}$ and NO_2 (95% CI)[2]
Road	1.039 (1.020-1.057)	1.032 (1.014-1.051)	1.031 (1.013-1.051)	1.034 (1.014-1.055)	1.034 (1.014-1.055)
Railway	1.024 (1.011-1.037)	1.020 (1.007-1.033)	1.019 (1.007-1.033)	1.020 (1.008-1.034)	1.020 (1.007-1.033)
Aircraft	0.971 (0.952-0.990)	1.025 (1.006-1.045)	1.024 (1.004-1.045)	1.026 (1.006-1.047)	1.025 (1.005-1.046)

[1] age as the underlying time scale

[2]Models additionally adjusted for sex, neighborhood index of socio-economic position, civil status, education level, mother tongue, nationality and the other noise sources.

Table S4: categorical HR for road traffic noise exposure and MI for models: not adjusted for air pollution (AP), adjusted for $PM_{2.5}$, adjusted for NO_2, and adjusted for $PM_{2.5}$ and NO_2

Road traffic	≤45 dB	45-50 dB	50-55 dB	55-60 dB	60-65 dB	>65 dB
Adjusted (no AP)	1	1.040 (0.982-1.100)	1.057 (1.002-1.115)	1.087 (1.029-1.148)	1.072 (1.012-1.135)	1.093 (1.028-1.162)
Adj for $PM_{2.5}$	1	1.039 (0.982-1.100)	1.057 (1.002-1.115)	1.086 (1.028-1.148)	1.071 (1.011-1.135)	1.092 (1.026-1.162)
Adj for NO_2	1	1.041 (0.983-1.102)	1.060 (1.004-1.118)	1.091 (1.031-1.153)	1.077 (1.015-1.142)	1.101 (1.032-1.176)
Adj for $PM_{2.5}$ and NO_2	1	1.041 (0.983-1.102)	1.059 (1.004-1.118)	1.090 (1.031-1.153)	1.077 (1.015-1.142)	1.102 (1.032-1.177)

Age as the underlying time scale and additionally adjusted for sex, neighborhood index of socio-economic position, civil status, education level, mother tongue, nationality and railway and aircraft noise.

Table S5: categorical HR for railway noise exposure and MI for models: not adjusted for air pollution (AP), adjusted for $PM_{2.5}$, adjusted for NO_2, and adjusted for $PM_{2.5}$ and NO_2

Railway	≤30 dB	30-40 dB	40-50 dB	50-60 dB	>60 dB
Adjusted (no AP)	1	1.030 (0.991-1.072)	1.066 (1.026-1.107)	1.034 (0.984-1.087)	1.070 (1.009-1.134)
Adj for $PM_{2.5}$	1	1.030 (0.989-1.071)	1.065 (1.024-1.107)	1.033 (0.982-1.086)	1.068 (1.007-1.133)
Adj for NO_2	1	1.033 (0.993-1.076)	1.069 (1.028-1.112)	1.036 (0.985-1.090)	1.072 (1.011-1.137)
Adj for $PM_{2.5}$ and NO_2	1	1.032 (0.992-1.075)	1.068 (1.027-1.111)	1.035 (0.984-1.088)	1.070 (1.009-1.135)

Age as the underlying time scale and additionally adjusted for sex, neighborhood index of socio-economic position, civil status, education level, mother tongue, nationality and road and aircraft noise.

Table S6: categorical HR for aircraft noise exposure and MI for models not adjusted for air pollution (AP), adjusted for $PM_{2.5}$, adjusted for NO_2, and adjusted for $PM_{2.5}$ and NO_2

Aircraft	≤30 dB	30-40 dB	40-50 dB	50-60 dB	>60 dB
Adjusted (no AP)	1	1.001 (0.952-1.053)	1.048 (1.007-1.091)	1.050 (0.978-1.127)	0.979 (0.827-1.159)
Adj for $PM_{2.5}$	1	1.000 (0.951-1.053)	1.047 (1.005-1.091)	1.049 (0.976-1.127)	0.978 (0.826-1.158)
Adj for NO_2	1	1.003 (0.953-1.056)	1.053 (1.009-1.098)	1.053 (0.980-1.131)	0.981 (0.829-1.161)
Adj for $PM_{2.5}$ and NO_2	1	1.002 (0.952-1.055)	1.051 (1.008-1.096)	1.051 (0.978-1.129)	0.978 (0.826-1.158)

Age as the underlying time scale and additionally adjusted for sex, neighborhood index of socio-economic position, civil status, education level, mother tongue, nationality and road and railway noise.

Table S7: linear HR for $PM_{2.5}$ and NO_2 (per 10 µg/m³) for MI in single exposure models, in models adjusted for noise, and in models adjusted for noise and the opposite air pollutant.

Air pollutant	Crude[1]	Single exposure model[2]	Adj for all noise sources[2]	Adj for all noise sources and for the other air pollutant[2]
$PM_{2.5}$	0.991 (0.955-1.029)	1.052 (1.013-1.093)	1.010 (0.969-1.052)	1.019 (0.971-1.071)
NO_2	0.968 (0.950-0.986)	1.024 (1.005-1.043)	0.996 (0.974-1.018)	0.990 (0.965-1.016)

[1]age as the underlying time scale

[2]Models additionally adjusted for sex, neighborhood index of socio-economic position, civil status, education level, mother tongue, and nationality.

Table S8: Adjusted* HR (95% confidence intervals) and number of deaths (N=) for NO_2 and road traffic noise for MI in categorical (quartiles) interaction exposure models. Cells with interaction terms[$] are shown in italics.

		Road traffic noise [dB]			
		≤49.0 (main effect) N=4249	**49.0-54.1 N=4775**	**54.1-60.3 N=5016**	**>60.3 N=5221**
NO_2 [μg/m³]	**≤22.3 (main effect) N=4728**	1.00 (reference) N=1834	1.04 (0.97-1.12) N=1287	1.05 (0.97-1.13) N=999	1.05 (0.96-1.15) N=608
	22.3-27.0 N=4643	1.02 (0.95-1.10) N=1181	*0.97 (0.87-1.08) N=1282*	*1.02 (0.92-1.15) N=1223*	*1.11 (0.98-1.26) N=957*
	27.0-32.3 N=4851	1.05 (0.96-1.14) N=848	*1.01 (0.90-1.13) N=1335*	*1.00 (0.89-1.12) N=1413*	*0.97 (0.85-1.10) N=1255*
	>32.3 N=5039	1.02 (0.91-1.14) N=386	*0.98 (0.85-1.12) N=871*	*1.00 (0.87-1.15) N=1381*	*0.98 (0.85-1.13) N=2401*

[*] Age as the underlying time scale and additionally adjusted for sex, neighborhood index of socio-economic position, civil status, education level, mother tongue, nationality, railway and aircraft noise, NO_2.

[$] Overall effects ($HR_{tot}$) in cells with interaction terms are obtained by multiplying the HR of these cells with the HRs of corresponding main effects (E.g. HR_{tot} for people in the highest NO_2 (>32.3 μg/m^3) and highest noise category (>60.3 dB): 0.98*1.02*1.05=1.05)