Short-term and long-term exposure to UFP around Schiphol Amsterdam airport health effect assessment

Flemming Cassee & Nicole Janssen

National Institute for Public Health and the Environment, Bilthoven, the Netherlands

Aviation emissions

Globally, air transport has been growing rapidly
- Both passengers and freight

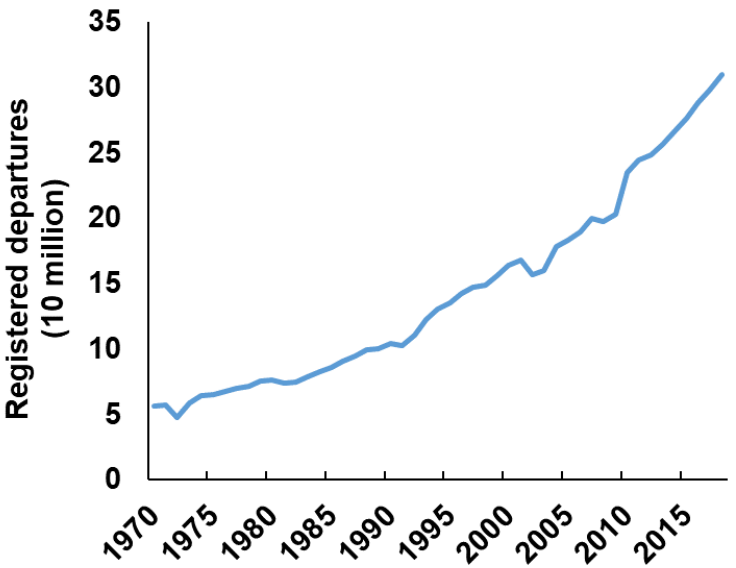
This results in huge increases in emissions of:
- Gases: CO, NO_x, SO_x, O_3
- Fine and ultrafine particulates (UFPs)

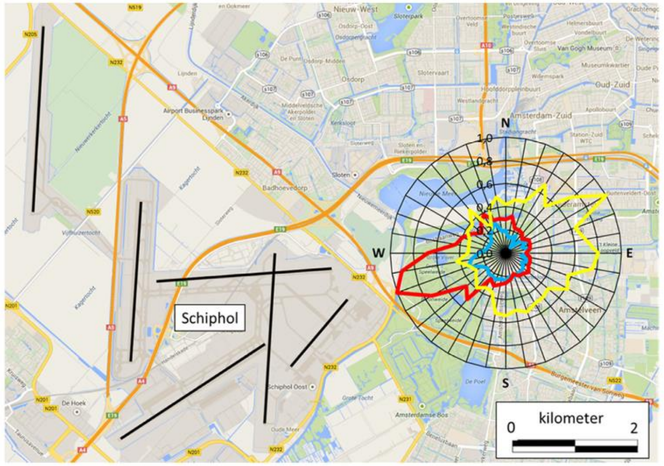
As well as those produced by:
- Ground service vehicles
- Passenger vehicles

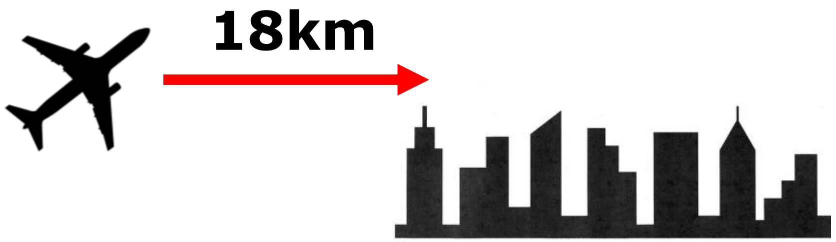
Exposure is concerning for airport staff
but also those living and working near by

› Aviation UFPs detected 18km away (Keuken et al. Atm Env, 2015)

› Including indoors







Aim of the programme

1. ***Measurements and modelling*** of long-term concentrations

2. Studies on ***acute exposure effects***
a) Study healthy young volunteers (Lammers et al, 2020+2021;Selley et al 2021)
b) Toxicological study on lung cells (He et al, 2020, Toxicol In Vitro)
c) Panel study primary school (children) (published in RIVM report only)

3. Studies on ***long-term exposure effects*** of UFP from aviation

www.rivm.nl/ultrafijnstofschiphol

Airport study

- Healthy young volunteers
- Amsterdam Schiphol airport

Summary of exposure variables. Values are averages for a 5-hr period as measured in the exposure cabin.

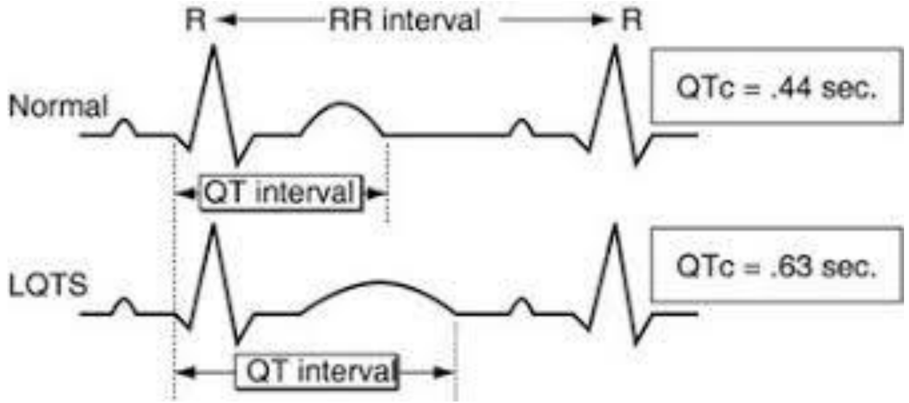
Exposure day	Mass	PNC	BC	NO_2	CO	SO_2	O_3	Temperature	rH
	(µg/m³)	(#/cm³)	(µg/m³)	(µg/m³)	(µg/m³)	(µg/m³)	(µg/m³)	(ºC)	(%)
Average	23.1	**53,469**	0.6	28.2	638	2.0	35.7	23.3	54
SD	8.3	43,776	0.4	12.2	83	0.9	14.4	2.7	7
Highest	47.5	**173,187**	1.9	60.2	830	3.2	78.6	28.6	66
Lowest	10.6	**10,520**	0.1	12.4	494	1.2	8.8	15.7	40

Mass concentrations are based on Filter measurements. PNC = particle number counts. See Method section for more details

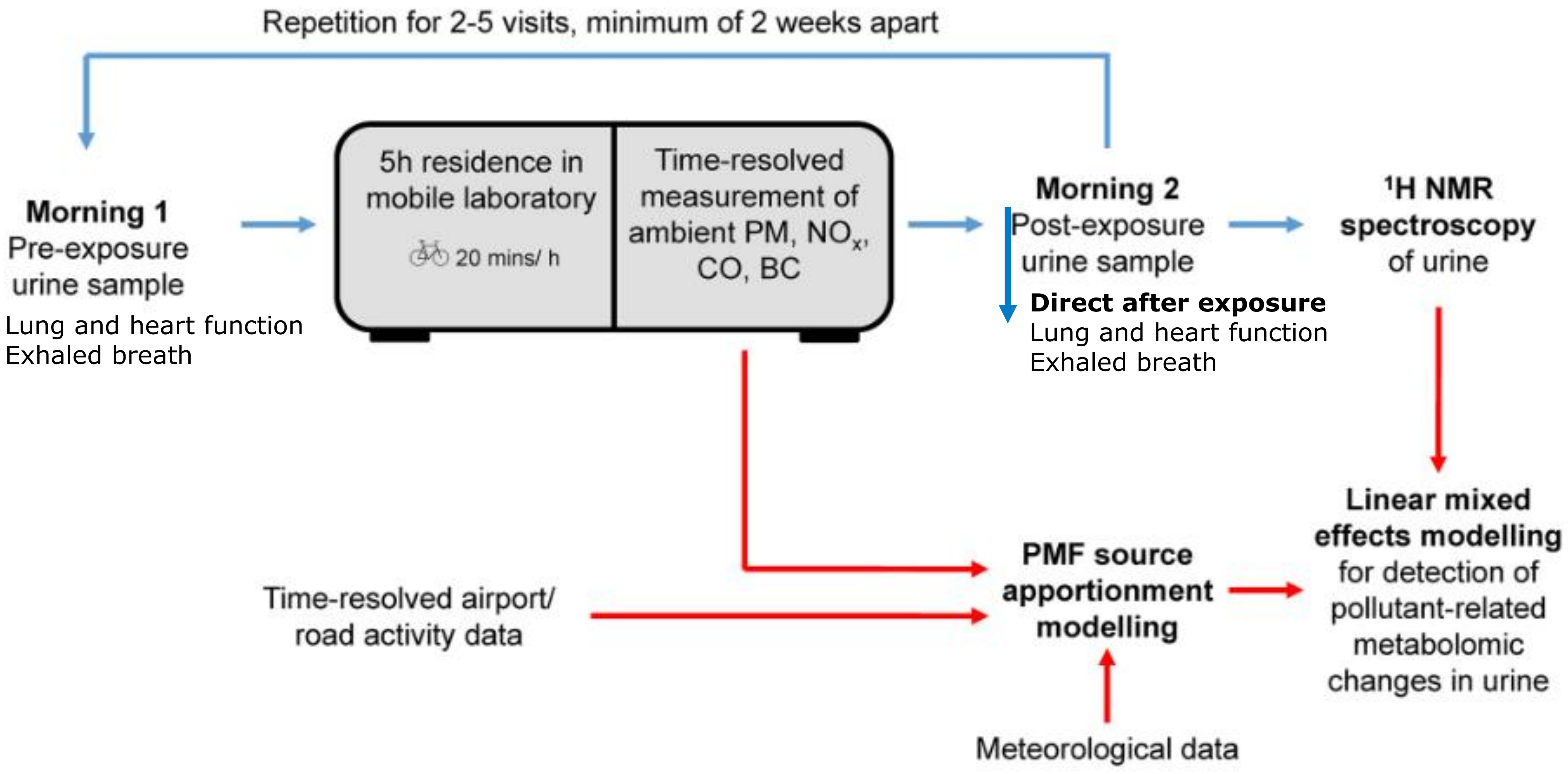
DL= Below the detection limit of the instrument

Measure health indicators

- Spirometry (lung function)
- Fractional exhaled nitric oxide (inflammation)
- ECG (heart function) & blood pressure
- Metabolome (oxidative stress) in urine



Airport study- young health volunteers



Environment International 141 (2020) 105779

Contents lists available at ScienceDirect

Environment International

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

Effects of short-term exposures to ultrafine particles near an airport in healthy subjects

A. Lammers[a], N.A.H. Janssen[b], A.J.F. Boere[b], M. Berger[a], C. Longo[a], S.J.H. Vijverberg[a], A.H. Neerincx[a], A.H. Maitland - van der Zee[a], F.R. Cassee[b,c,*]

BOLD = statistically significant

Single-pollutant models

Outcome	PNC[a] N = 86 Est.	95%CI			BC[b] N=86 Est.	95%CI			NO_2[c] N = 86 Est.	95%CI		
FVC (mL)	**-5.88**	**-11.06**	**–**	**-0.03**	38.96	-23.67	–	101.60	0.57	-20.78	–	21.92
FEV1 (mL)	-4.04	-9.33	–	2.38	27.68	-28.96	–	100.50	-11.09	-30.77	–	16.78
FEV1/VC	0.00	0.00	–	0.00	0.00	-0.01	–	0.01	0.00	0.00	–	0.00
PEF (L/s)	-0.01	-0.03	–	0.02	0.16	-0.08	–	0.42	-0.05	-0.12	–	0.05
FeNO (ppb)	0.02	-0.09	–	0.14	0.24	-0.96	–	1.61	0.28	-0.12	–	0.72
$HR_{sitting}$ (bpm)	-0.09	-0.37	–	0.19	-1.39	-4.43	–	2.39	-0.40	-1.46	–	0.82
Saturation (%)	0.00	-0.04	–	0.05	0.08	-0.47	–	0.57	-0.04	-0.21	–	0.14
BP_{sys} (mmHg)	-0.14	-0.38	–	0.08	**3.18**	**0.49**	**–**	**5.74**	0.81	-0.12	–	1.72
BP_{dia} (mmHg)	-0.14	-0.37	–	0.10	**2.90**	**0.22**	**–**	**5.55**	**1.12**	**0.23**	**–**	**2.05**
ECG - HR (bpm)	0.27	-0.03	–	0.61	0.78	-2.98	–	4.61	0.04	-1.18	–	1.33
ECG - PR (ms)	-0.17	-0.58	–	0.15	**4.81**	**1.37**	**–**	**10.25**	0.99	-0.36	–	2.54
ECG - QRS (ms)	0.10	-0.10	–	0.30	-1.20	-3.53	–	1.13	0.06	-0.73	–	0.86
ECG - QTc (ms)	**0.79**	**0.16**	**–**	**1.52**	0.43	-7.26	–	9.01	-0.04	-2.64	–	2.82

outcome	PM2.5[c] N=86 Est	95% CI			CO[d] N=86 Est.	95%CI			O_3[c] N=86 Est.	95%CI		
FVC (mL)	22.74	-6.96	–	52.44	10.47	-345.99	–	366.92	2.98	-17.74	–	23.71
FEV1 (mL)	26.32	-2.39	–	58.27	7.67	-355.71	–	377.43	6.72	-15.37	–	26.76
FEV1/VC	0.00	0.00	–	0.01	0.00	-0.04	–	0.04	0.00	0.00	–	0.00
PEF (L/s)	0.02	-0.10	–	0.14	-0.37	-1.86	–	0.93	0.03	-0.05	–	0.11
FeNO (ppb)	-0.30	-0.88	–	0.30	-0.54	-7.34	–	6.65	-0.36	-0.75	–	0.04
$HR_{sitting}$ (bpm)	0.17	-1.32	–	1.59	2.78	-15.05	–	20.25	**1.16**	**0.11**	**–**	**2.09**
Saturation (%)	0.00	-0.25	–	0.23	0.52	-2.34	–	3.27	-0.09	-0.27	–	0.07
BP_{sys} (mmHg)	-0.21	-1.48	–	0.96	10.61	-4.72	–	24.36	-0.22	-1.09	–	0.61
BP_{dia} (mmHg)	0.05	-1.22	–	1.24	11.60	-3.50	–	25.64	**-1.09**	**-1.94**	**–**	**-0.29**
ECG - HR (bpm)	0.36	-1.48	–	1.91	8.66	-11.50	–	28.33	-0.01	-1.18	–	1.12
ECG - PR (ms)	0.13	-1.94	–	1.79	2.26	-20.51	–	23.68	-0.12	-2.03	–	1.05
ECG - QRS (ms)	0.10	-0.99	–	1.19	1.04	-11.97	–	14.05	-0.23	-0.98	–	0.51
ECG - QTc (ms)	0.60	-3.16	–	4.02	16.24	-24.94	–	61.48	0.83	-1.75	–	3.25

Results of the single pollutant models were corrected for room temperature and relative humidity respiratory symptoms, age, gender and BMI.
a= per 10,000 particles/cm^3 ; b = per 1 μg/m^3; c = per 10 μg/m^3; d= per 1000 μg/m^3. Numbers in bold are significant ($p<0.05$)

Correlations stable in 2-pollutant models

$$QTc = \frac{QT\ measured}{\sqrt{RR_{(in\ seconds)}}}$$

risk of ventricular dysrhythmia and sudden death.

Short-term and long-term exposure to UFP of Schiphol Amsterdam airport

Size seperated effect estimates

Two-pollutant model consisting of two particle size fractions (adjusted).

Outcome	PNC ≤ 20 nm Adjusted for PNC > 50 nm				PNC > 50 nm Adjusted for PNC ≤ 20 nm			
	Est.	95%CI			Est.	95%CI		
FVC (mL)	**−72.1**	**−140.2**	**–**	**−2.8**	37.2	−47.7	–	124.5
FEV_1 (mL)	−49.6	−117.0	–	27.1	16.0	−69.9	–	110.7
PEF (mL/s)	−19.2	−310.7	–	248.3	71.3	−272.0	–	421.3
FeNO (ppb)	0.0	−1.3	–	1.4	−0.7	−2.4	–	1.1
$HR_{sitting}$ (bpm)	−1.5	−5.1	–	1.8	1.8	−2.9	–	6.1
Saturation (%)	0.1	−0.4	–	0.8	−0.4	−1.1	–	0.4
BP_{sys} (mmHg)	−1.9	−4.8	–	0.8	2.9	−0.7	–	6.8
BP_{dia} (mmHg)	−2.3	−5.2	–	0.5	**3.7**	**0.1**	**–**	**7.5**
ECG – HR (bpm)	3.0	−0.7	–	7.0	−1.1	−6.1	–	3.8
ECG – PR (ms)	−3.3	−8.3	–	0.5	0.5	−5.8	–	5.8
ECG – QRS (ms)	1.1	−1.5	–	3.6	0.9	−2.3	–	4.1
ECG – QTc (ms)	**9.9**	**2.1**	**–**	**18.7**	−3.4	−13.5	–	8.0

Data are presented as estimates (est.) and 95% confidence intervals (CI). All effect estimates are scaled to the 5-95th percentile change in the exposure of interest and are adjusted for age, sex, BMI, respiratory symptoms, room temperature and room humidity. Numbers in bold are significant effects ($p < 0.05$). PNC = particle number concentration; FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 s; PEF = peak expiratory flow rate; FeNO = fractional exhaled nitric oxide; HR = heart rate; BPsys = systolic blood pressure; BPdia = diastolic blood pressure; ECG = electrocardiography; QTc = corrected QT. PNC size fractions were measured by a scanning mobility particle sizer (SMPS) with a limit of detection of 6–225 nm.

International Journal of Hygiene and Environmental Health 237 (2021) 113803

Contents lists available at ScienceDirect

ELSEVIER

International Journal of Hygiene and Environmental Health

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

Check for updates

Alterations to the urinary metabolome following semi-controlled short exposures to ultrafine particles at a major airport

Liza Selley[a,*,1], Ariana Lammers[b,1], Adrien Le Guennec[c], Milad Pirhadi[d], Constantinos Sioutas[d], Nicole Janssen[e], Anke H. Maitland - van der Zee[b], Ian Mudway[f,g], Flemming Cassee[e,h]

To identify changes to the human urinary metabolome that accompany exposure to UFP at Amsterdam Schiphol Airport

To establish which emissions sources are responsible for these changes

Impact of major pollutants on urinary metabolome

Total PNC associated with reductions in urinary taurine and dimethylamine concentration – **oxidative stress** indictors

- This effect was attributable to UFP within **the 6-20 nm** fraction
- But **not larger** particles. Pollutant gases had distinct and smaller effects than PNC

Metabolite	Total PNC (5-95p = 120,280 particles/ cm^3)	PNC < 20nm (5-95p = 51,160 particles/ cm^3)	PNC > 50nm (5-95p = 3,900 particles/ cm^3)
	Coef. (lower – upper CI)	**Coef. (lower – upper CI)**	**Coef. (lower – upper CI)**
Taurine	**-0.263 (-0.507 – -0.020)**	**-0.298 (-0.550 – -4.709)**	-0.044 (-0.396 – 0.307)
Dimethylamine	**-0.023 (-0.040 – -0.067)**	**-0.023 (-0.040 – -0.067)**	0.006 (-0.018 – 0.029)
Unassigned N-acetylated compound	0.000 (-0.002 – 0.002)	-0.001 (-0.002 – 0.001)	0.000 (-0.002 – 0.003)
3-Hydroxyisovalerate	-0.001 (-0.005 – 0.004)	0.000 (0.000 - 0.000)	-0.002 (-0.008 – 0.004)
3-Hydroxyisobutyrate	-0.002 (-0.005 – 0.001)	-0.002 (-0.005 – 0.002)	-0.002 (-0.006 – 0.002)
N-Acetylglutamine	0.000 (-0.015 – 0.015)	0.002 (-0.014 – 0.017)	0.001 (-0.022 – 0.023)

Source apportionment: Pirhadi et al

Pirhadi *et* al. used a positive matrix factorisation source apportionment model to calculate PNCs for different emission sources at the airport

- Time resolved PNC size distribution data, auxiliary pollutant concentrations, aircraft arrival/departure timings, highway traffic counts, meteorological data


Environmental Pollution 260 (2020) 114027

Contents lists available at ScienceDirect

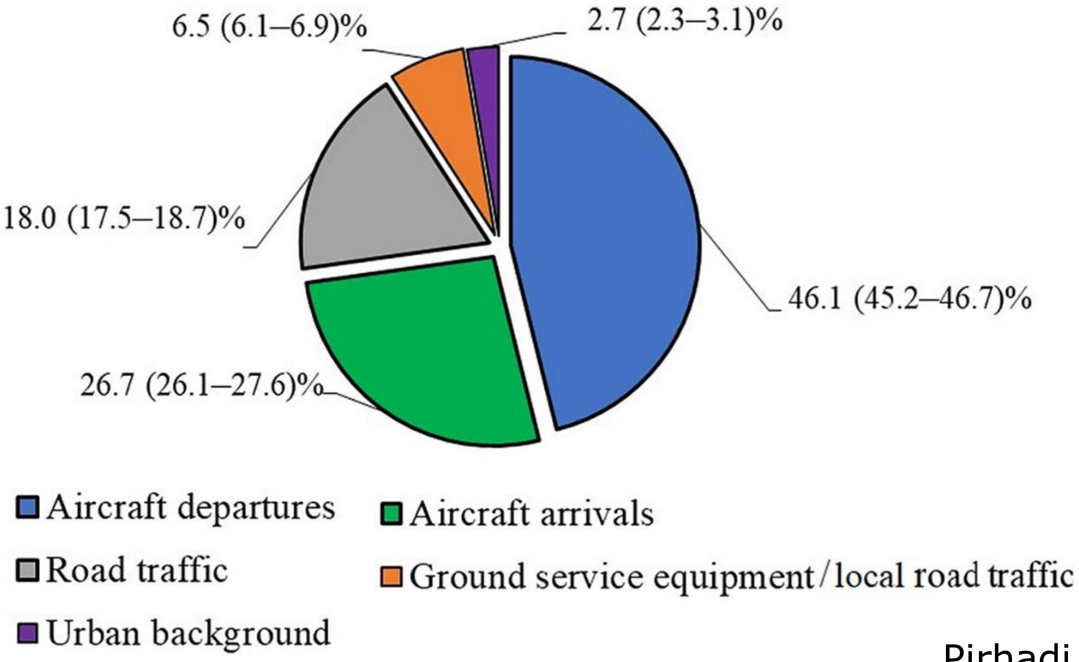
Environmental Pollution

ELSEVIER

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

Relative contributions of a major international airport activities and other urban sources to the particle number concentrations (PNCs) at a nearby monitoring site☆

Milad Pirhadi [a], Amirhosein Mousavi [a], Mohammad H. Sowlat [a], Nicole A.H. Janssen [b], Flemming R. Cassee [b, c], Constantinos Sioutas [a, *]



Pirhadi *et al.* 2020, DOI: 114027

Metabolomic change is dependent on flight behaviours

- Focusing on **landing UFPs** doubles the association with reductions in urinary taurine concentration

	Landing PNC (5-95p = 31200 particles/ cm^3)		
	Single pollutant model	Accounting for airport traffic PNC (5-95p= 5077 particles/ cm^3)	Accounting for non-airport traffic PNC (5-95p= 15290 particles/ cm^3)
	Coef. (lower – upper CI)	Coef. (lower – upper CI)	Coef. (lower – upper CI)
Taurine	**-0.413 (-0.689 - -0.136)**	-0.414 (-0.692 - -0.136)	-0.414 (-0.692 - -0.136)
Dimethylamine	**-0.031 (-0.049 - -0.013)**	-0.031 (-0.049 - -0.012)	-0.031 (-0.050 - -0.013)
Pyroglutamate	-0.004 (-0.010 - 0.002)	-0.002 (-0.004 - < 0.000)	-0.002 (-0.004 - 0.000)
Isocitrate	0.001 (-0.001- 0.003)	0.001 (-0.001 - 0.004)	0.002 (-0.001 - 0.004)
2-hydroxyisobutyrate	-0.001 (-0.004 - 0.002)	-0.001 (-0.004 - 0.002)	-0.001 (-0.004 - 0.002)

- The associations with energy metabolism and fuel additive exposure are not present

Metabolomic change is dependent on flight behaviours

- UFPs produced during **take-off** do not associate significantly with reduced urinary taurine
  - Perhaps due to compositional differences

	Take-off PNC (5-95p= 56130 particles/ cm^3)		
	Single pollutant model	**Accounting for airport traffic PNC** (5-95p= 5077 particles/ cm^3)	**Accounting for non-airport traffic PNC** (5-95p= 15290 particles/ cm^3)
Metabolite	**Coef. (lower – upper CI)**	**Coef. (lower – upper CI)**	**Coef. (lower – upper CI)**
Taurine	-0.224 (-0.495 - 0.047)	-0.223 (-0.494 - 0.047)	-0.232 (-0.513 - 0.050)
Dimethylamine	**-0.019 (-0.037 - -0.001)**	-0.019 (-0.037 - -0.001)	-0.020 (-0.038 - -0.001)
Pyroglutamate	**-0.006 (-0.012 - -0.001)**	-0.006 (-0.012 - -0.001)	-0.008 (-0.014 - -0.002)
Isocitrate	0.001 (-0.001 - 0.003)	0.001 (-0.001 - 0.003)	**0.002 (> 0.000- 0.004)**
2-hydroxyisobutyrate	-0.002 (-0.005 - > 0.000)	-0.002 (-0.005 - < 0.000)	**-0.003 (-0.006 - < 0.000)**

- Accounting for co-exposure to UFPs from non-airport traffic unmasked associations with TCA cycle activity and a potential marker of fuel additive exposure

Summary airport study acute exposures

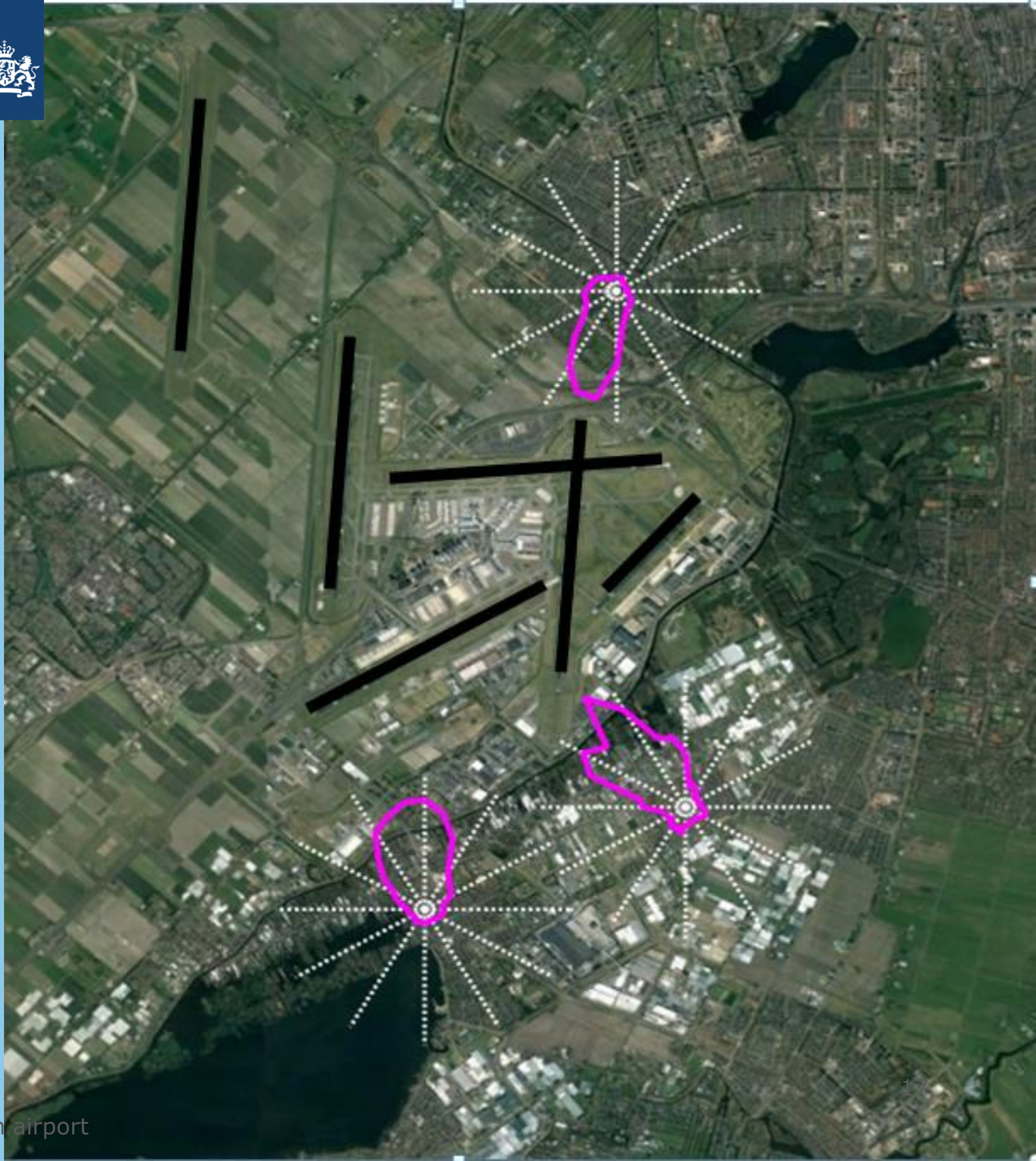
Health marker	Location	UFP aircrafts	UFP road traffic
Among school children (panel study			
Daily symptoms	Home	**Yes, especially for wheezing and phlegm giving up**	**Yes, especially for wheezing and shortness of breath at rest**
Medication use	Home	**Yes**	**Yes**
Daily long function	Home	**No**	**Yes, in de morning**
Longfunction, under supervision	School	**No, not consistent**	**No, not consistent**
NO exhaled air	School	**No, inconsistent for children with and without asthma**	**No, inconsistent for children with and without asthma**
Research among healthy adults (volunteer study)			
Long function	Near the airport	**Yes, decrease FVC**	**No**
NO exhaled air; oxygen saturation		**No**	**No**
Heart function		**Yes, extended QTc**	**No, not consistent**
Blood pressure		**No**	**Yes**
Urine Oxidative stress		**Yes**	**Yes, less evident**
Toxicological research lung cells		Degree of harmfulness	
Cell damage and production of signaling substances for acute inflammatory reactions	Near Schiphol and at the source	Yes, but no apparent differences in reactivity between UFP collected at different wind directions (airport vs. non-airport) and directly from a turbine engine	

Conclusions acute exposure studies

- Short-term high exposure to UFP, such as occurs in the Schiphol region, can lead to effects on the respiratory system (in both adults and children).

- Indications have been found for effects on the cardiovascular system in adults

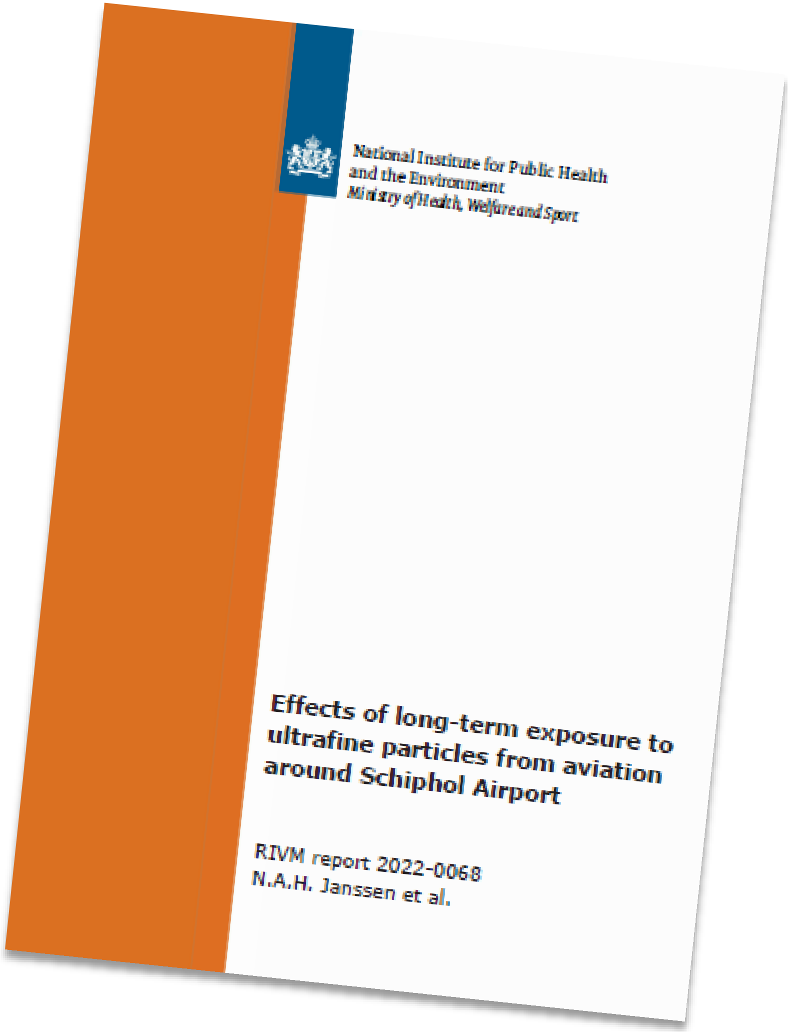
- There are no clear indications that the health effects of UFP from air traffic are substantially different from those of UFP from road traffic. Potency may differ.



Long-term exposures

Research question
What are the health effects of long-term exposure to **<u>UFP from aviation</u>** near Schiphol Airport?

Design
Modelled concentrations of UFP from aviation at the residential address (report I) linked to existing health registries and surveys


National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Effects of long-term exposure to ultrafine particles from aviation around Schiphol Airport

RIVM report 2022-0068
N.A.H. Janssen et al.

Study on health effects long-term exposure

- ❑Mortality
- ❑Medication use (as proxy voor chronic disease
- ❑Pregnancy outcomes
- ❑Health monitor (questionnaires)

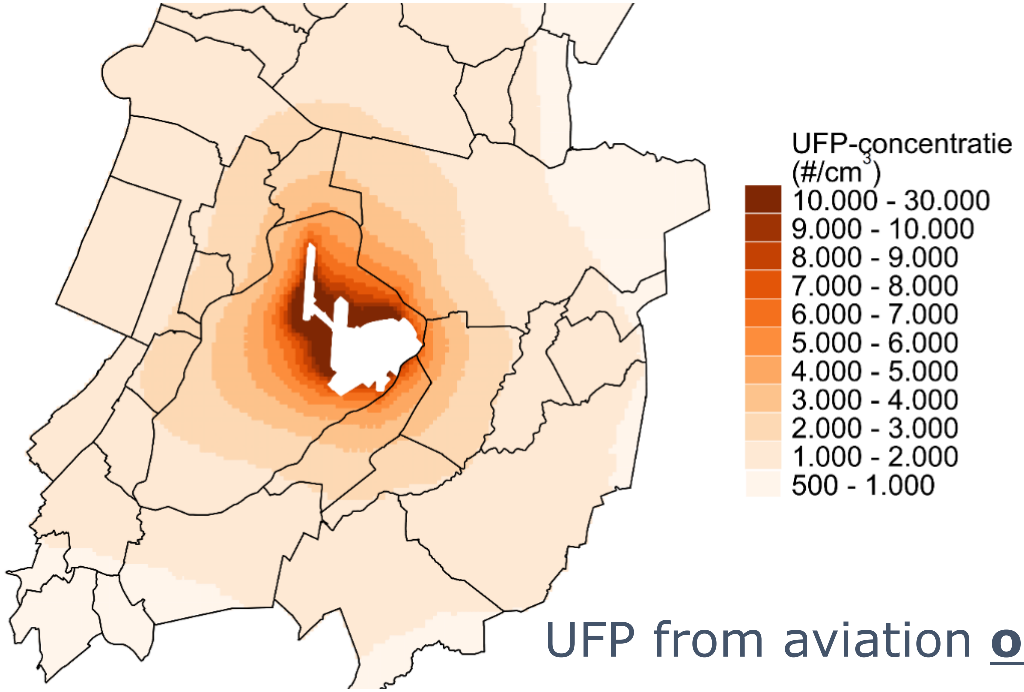
perined

Loket Gezondheidsmonitors

Study area

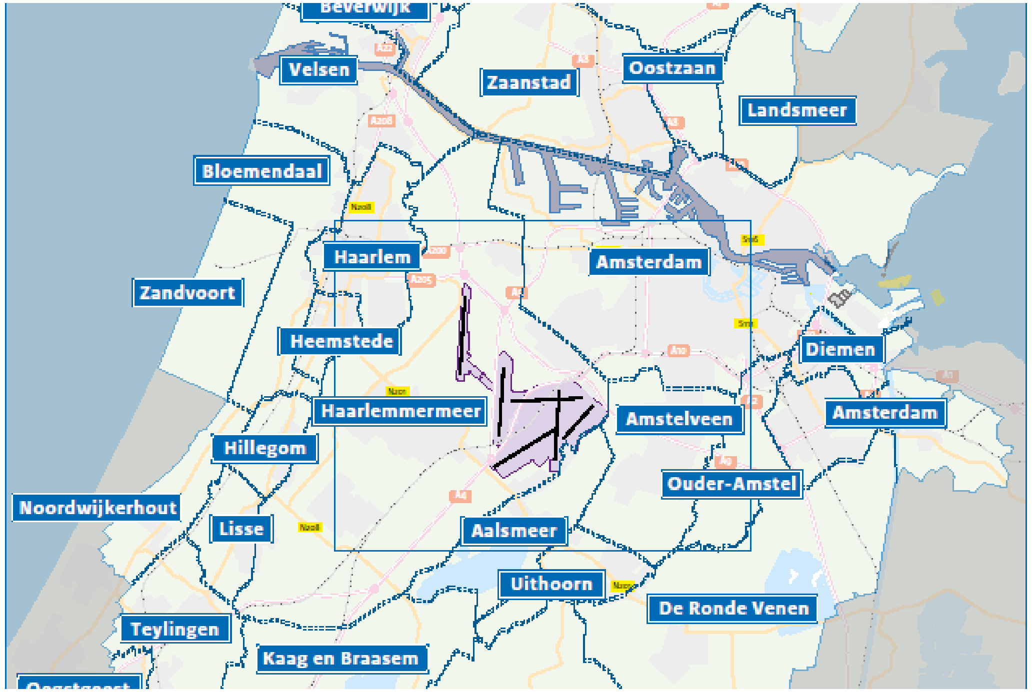
31 MUNICIPALITIES, OVER 2 MILLION RESIDENTS

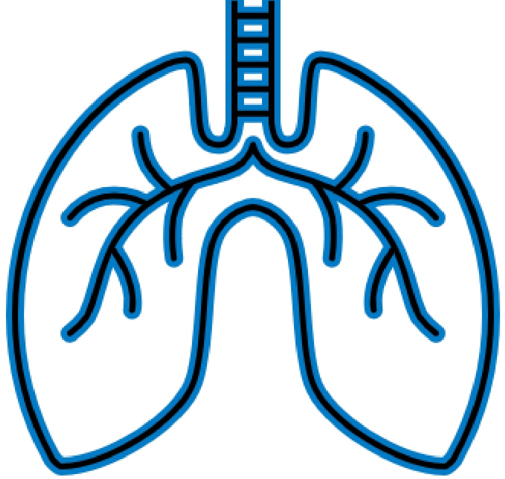
EXPOSURE ESTIMATED FOR ALL ADDRESSES IN THE AREA PERIOD 2003-2019



UFP from aviation **only**

UFP FROM AVIATION IN THE STUDY AREA





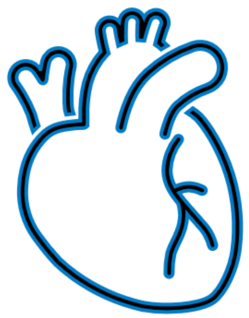
Respiratory system

- **No indications** that long-term exposure to UFP from air traffic around Schiphol causes respiratory diseases
  - Mortality: total respiratory disease, COPD, lung cancer
  - Morbidity: asthma (medication use and self reported)

Cardiovascular and birth outcomes

› Long-term exposure to airport related UFP:
suggestive evidence

– Heart rhythm disorder, Ischemic heart disease
– Heart attack, cerebrovascular disease, stroke



– Preterm birth, low birth weight, birth defects

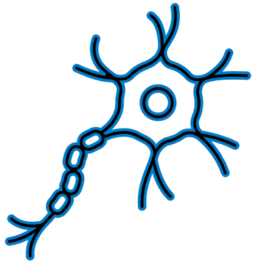
Medication heart disease in 12 year per 1000 people

(Excess risk: 1,025 per 3.500 #/cm^3)

4 on top of 160

LOW EXPOSURE

HIGH EXPOSURE



Neurological effects and Diabetes

- Long-term research: **insufficient evidence**
  - Mortality and medication use related to dementia, Parkinson’s and Alzheimer’s disease
  - Psychological stress / anti-depressants
  - Medication use

General health effects and mortality

- Long-term exposure: **no indications**
  - All-cause mortality
  - Self perceived health

Summary long-term exposure effects

Health effects	Long-term exposure
Respiratory disorders	No indication
Cardiovascular diseases	Sugestive evidence
Birth outcomes	Sugestive evidence
Neurological effects & psychological complaints	Insuffcient evidence
Diabetes	Insuffcient evidence
General (perceived) health effects	No indications

Overall conclusions

- Exposure to UFP from air traffic around Schiphol can potentially lead to adverse effects on the cardiovascular system and on the growth and development of the fetus
- Short-term exposure to UFP from air traffic can lead to respiratory effects.
- Based on the studies on short-term exposure, there are no indications that the health effects of UFP from air traffic are significantly different from those of UFP from road traffic. Potency may differ.
- No evidence of effects of long-term exposure on the respiratory tract
- There is insufficient evidence for effects of long-term exposure to UFP from air traffic on the nervous system and metabolism (diabetes)
- No evidence for effects of long-term exposure to UFP from air traffic on total mortality, mortality around birth and perceived health (general health)

Thanks for your attention

Universiteit Utrecht

amc

GGD Amsterdam

Erbrink Stacks Consult

TNO innovation for life

GGD Kennemerland

nlr

Gemeente Aalsmeer

USC University of Southern California

BARIN

Omgevingsdienst noordzeekanaalgebied

Schiphol Group

Gemeente Amstelveen

Gemeente Amsterdam

Bewoners Omgeving Schiphol

Provincie Noord-Holland

natuur en milieu federatie noord-holland

gemeente Haarlemmermeer

KLM

HARVARD T.H. CHAN SCHOOL OF PUBLIC HEALTH

Helmholtz Instituut

UHASSELT KNOWLEDGE IN ACTION

UNIVERSITY OF COPENHAGEN

1. Conclusions

For a number of health outcomes there is suggestive evidence of adverse effects due to long-term exposure to UFP from aviation around Schiphol. This warrants further investigation, preferable in studies around multiple large (international) airports. More specifically:

- For cardiovascular disease, we conclude that there is suggestive evidence for effects of exposure to UFP from aviation around Schiphol airport, based on the joint results of this study, our volunteer study near Schiphol airport, as well as the literature on both short-term and long-term effects of UFP in general.
- For pregnancy outcomes, we conclude that there is suggestive evidence for effects of exposure to UFP from aviation during pregnancy. This is based on the results of this study and on results of other studies on UFP in relation to pregnancy outcomes, including a study near another airport.
- For respiratory disease, we conclude that there are no indications that long-term exposure to UFP from aviation around Schiphol airport causes this type of disease, but short-term exposure may aggravate respiratory symptoms and increase medication use in residents that already have the disease.
- For metabolic disease, we conclude that there is inadequate evidence for effects of long-term exposure to UFP from aviation around Schiphol airport, based on the results of the current study and limited literature.
- For neurodegenerative disease and psychological complaints, we conclude that there is inadequate evidence for effects of long-term exposure to UFP from aviation around Schiphol Airport.
- For the three indicators of general health (natural mortality, infant mortality, and self-perceived health), we conclude that there are no indications of effects of long-term exposure to UFP from aviation around Schiphol Airport.

Associations were generally insensitive to adjustment for other air pollutants and noise, providing evidence for independent effects of UFP.