Exposure to Air Pollution and its Impact on Childhood Mental Health

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Outline

- Air Pollution and the Brain
- Cincinnati Childhood Allergy and Air Pollution Study (CCAAPS)
  - Study design
  - Air pollution modeling
  - Childhood exposure to air pollution and mental health at age 12
- Acute Exposure to Air Pollution and Childhood Mental Health
- Personal Exposure to Ultrafine Particles
  - Ecological Momentary Assessment and Personal Particle Exposure (EcoMAPPE) Study
  - Reporting Back Individual Results of Personal Air Monitors

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Burden of Air Pollution

- Near ubiquitous environmental exposure
- Ambient $PM_{2.5}$ was the 5th-ranking mortality risk factor in 2015
  - 4.2 million deaths
  - ↓ 103.1 million disability-adjusted life-years
- Estimates of burden based on
  - Ischemic heart disease
  - Cerebrovascular disease
  - Lung cancer
  - Chronic obstructive pulmonary disease
  - Lower respiratory infections

Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015

Aaron J Cohen*, Michael Brauer*, Richard Burnett, H Ross Anderson, Joseph Frostad, Kara Estep, Kalpana Balakrishnan, Bert Brunekreef, Lalit Dandona, Rakhi Dandona, Valery Feigin, Greg Freedman, Bryan Hubbell, Amelia Jobling, Haidong Kan, Luke Knibbs, Yang Liu, Randall Martin, Lidia Morawska, C Arden Pope III, Hwashin Shin, Kurt Straif, Gavin Shaddick, Matthew Thomas, Rita van Dingenen, Aaron van Donkelaar, Theo Vos, Christopher J L Murray, Mohammad H Forouzanfar†

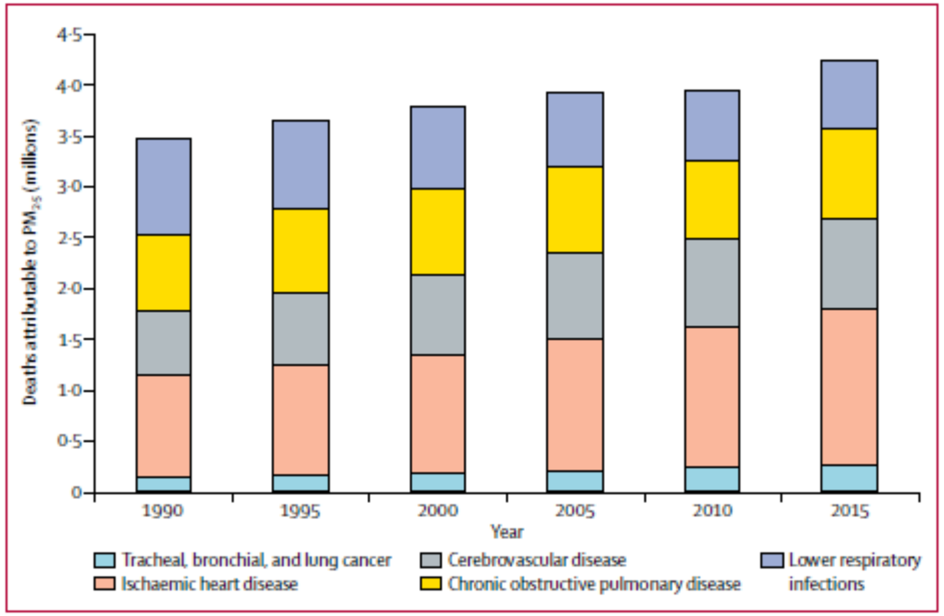
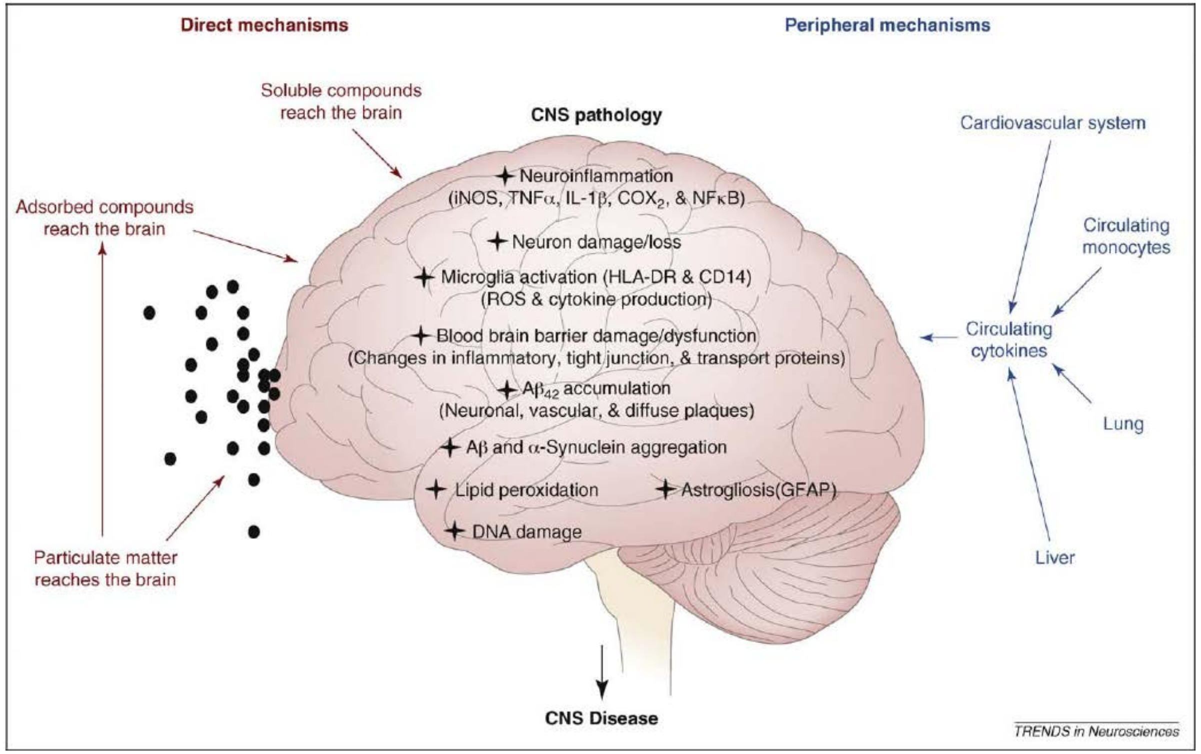


Figure 4: **Deaths attributable to ambient particulate matter pollution by year and cause**

Cohen et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet*. 2017;389:1907-18.

Air Pollution and the Central Nervous System



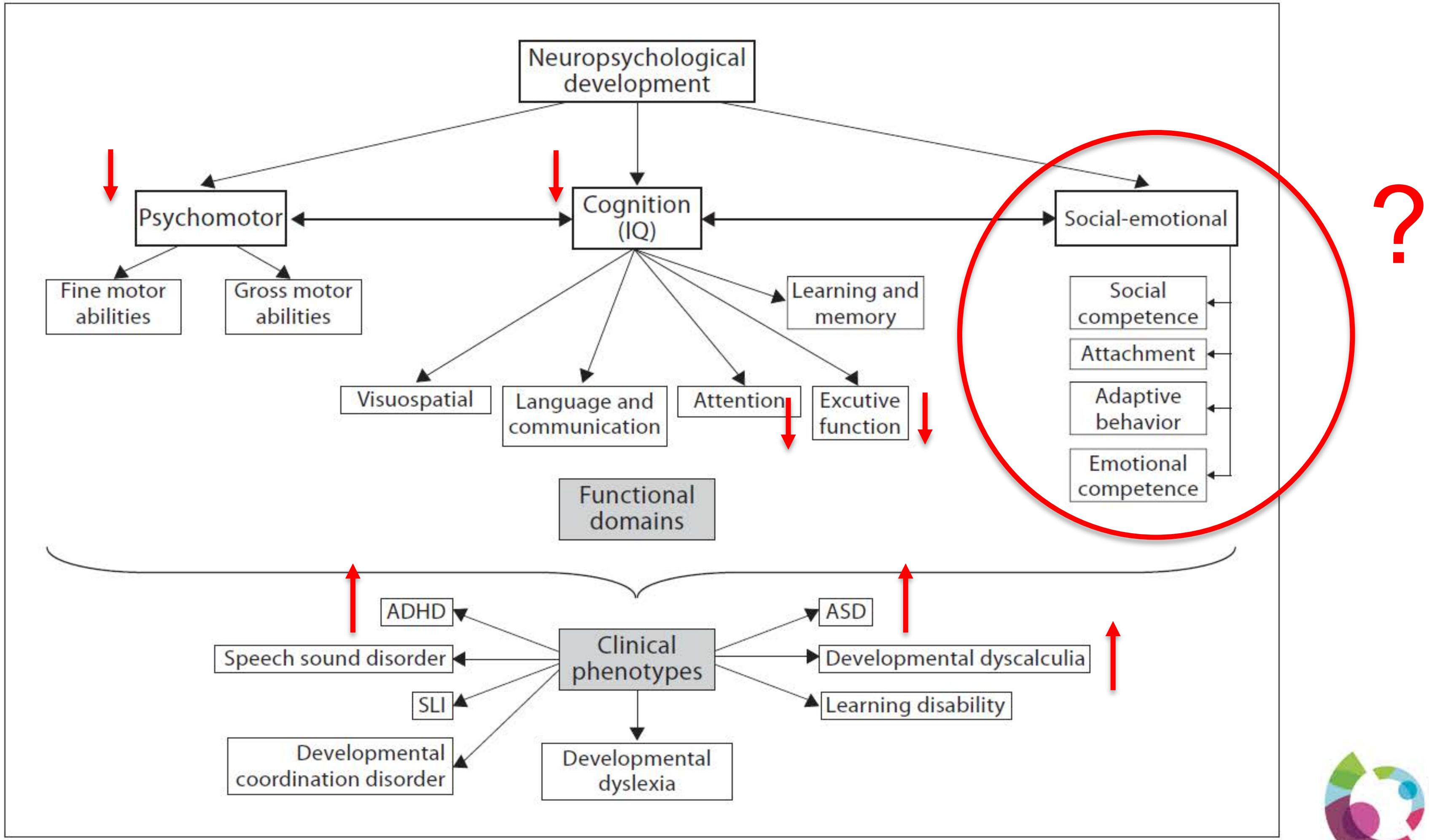
Block and Calderon-Garciduenas. *Trends in Neurosciences*. 2009;32:506-516.

- Air pollutants of concern
  - PM$_{2.5}$
  - Traffic-related air pollution
    - Elemental carbon
    - Ultrafine particles (UFP, PM$_{0.1}$)

- Mechanisms
  – Direct: Particles and absorbed compounds direct exposure to the brain
  – Indirect mechanisms: Inflammatory response in peripheral organ systems

- Exposure to neurotoxicants during brain development may manifest as functional impairments later in life

Neurodevelopmental Outcomes Associated with Air Pollution

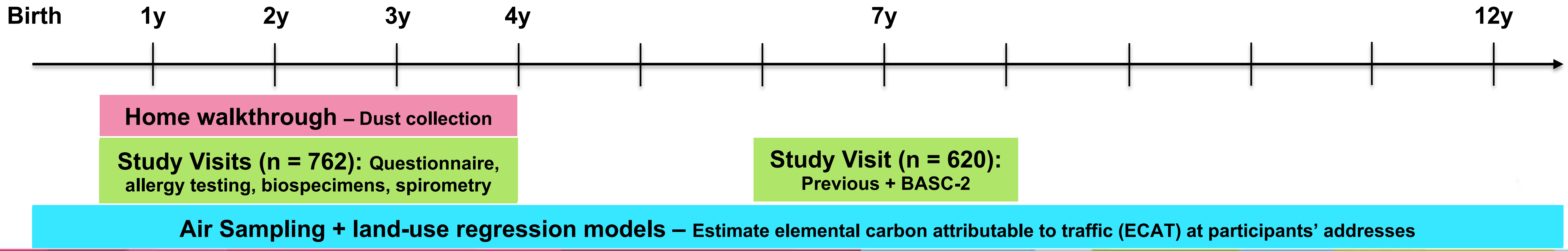


Forns et al. A Conceptual framework in the Study of Neuropsychological development in Epidemiological Studies. *Neuroepidemiology*. 2012;38:203-8.

Cincinnati Childhood Allergy and Air Pollution Study (CCAAPS)

- Determine if children exposed to traffic-related air pollution, specifically diesel exhaust particles, are at increased risk for
  - Allergic diseases and asthma
  - Adverse neurodevelopmental outcomes

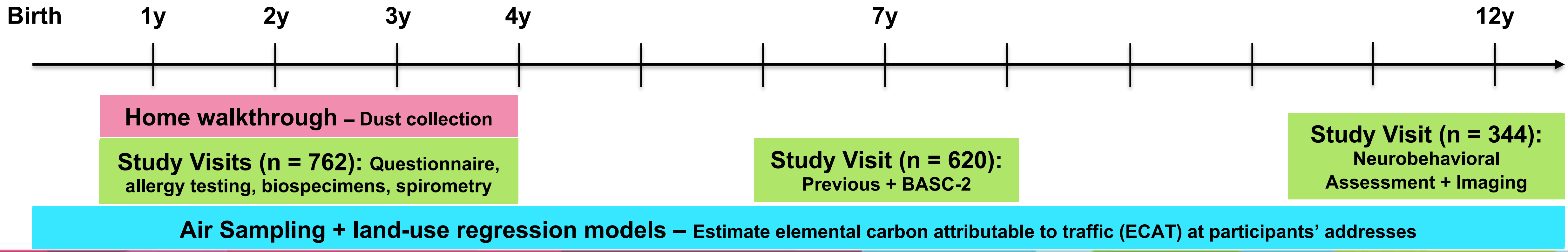
- Longitudinal cohort of infants born 2001-2003 in greater Cincinnati, OH, USA
  - Birth record address < 400 m major road or > 1500 m from major road



Child Direct Assessments	Outcome / Assessment
Wechsler Intelligence Scale for Children (WISC-IV)	Full scale IQ and subscales
Conner's Continuous Performance Test (Conner's CPT)	Inattentiveness, impulsivity, sustained attention
Children's Depression Inventory (CDI-II)	Cognitive, affective, and behavioral signs of depression
Spence Children's Anxiety Scale (SCAS)	Generalized anxiety and subscales
Grooved Pegboard Test	Eye-hand coordination and motor speed
Wide Range Achievement Test (WRAT-4)	Word reading and sentence comprehension
Children's Sleep Habits Questionnaire (CSHQ)	Sleep problems in school-aged children
Caregiver Survey about Child	**Outcome / Assessment**
Behavior Assessment System for Children (BASC-2)	Behavioral and emotional function
Behavior Rating Inventory of Executive Function (BRIEF)	Executive function in children
Children's Sleep Habits Questionnaire (CSHQ)	Sleep problems in school-aged children
Parenting Relationship Questionnaire (PRQ)	Parent-child relationship and rearing environment
Social Responsiveness Scale (SRS)	Social impairment and behaviors associated with ASD
Caregiver Direct Assessment	**Outcome / Assessment**
Wechsler Abbreviated Scale of Intelligence (WASI-2)	Full scale IQ
Beck Depression Inventory – 2nd Ed. (BDI-II)	Measure of depression in adults

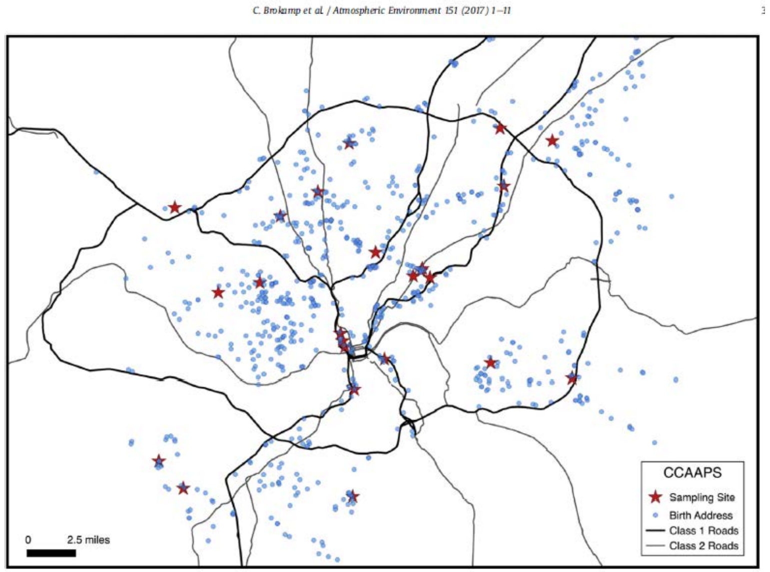
+

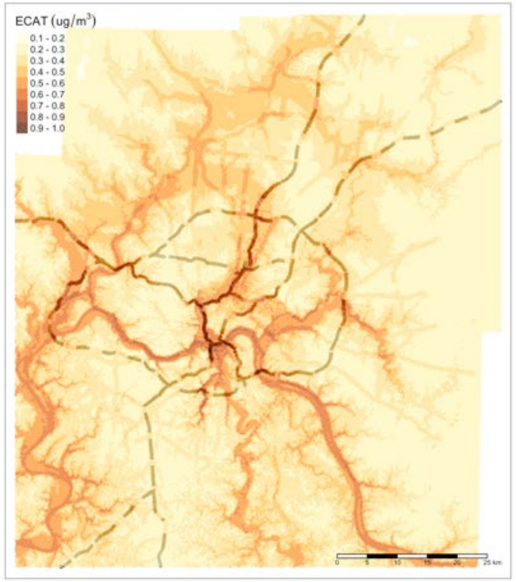
Sequences Acquired	Imaging Outcome
Three dimensional T1 weighted imaging	Whole brain and substructure volumes
Standard T2 weighted	Inflammatory changes noted with hyperintense signals
T2 map for quantitative T2 measurements	T2 rates for brain tissues
Diffusion Tensor Imaging of White Matter	White matter integrity metrics
Magnetic Resonance Spectroscopy	Metabolite concentrations
Functional Magnetic Resonance Imaging Verb generation task	Neural activation levels

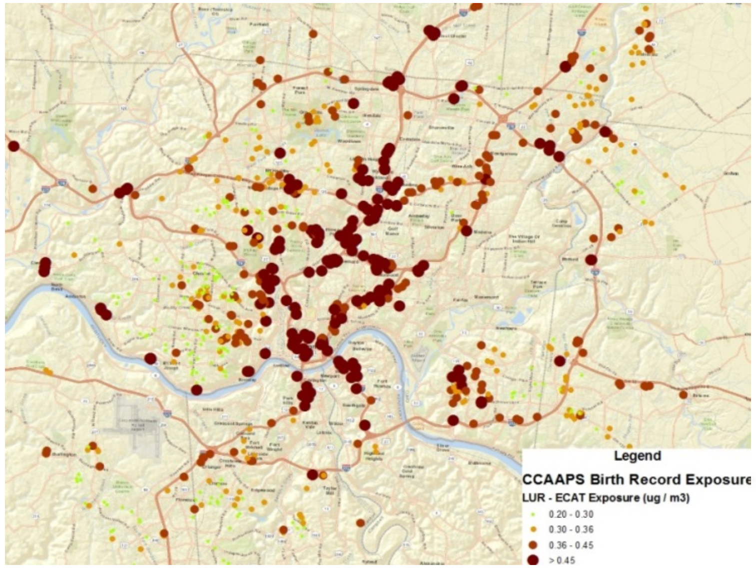


Traffic-Related Air Pollution (TRAP)

- Ambient air sampling campaign (2001-2006) at 27 sampling sites
  - Elemental carbon attributable to traffic (ECAT)
    - 24-hour concentrations (μg/m^3) averaged over 5-year sampling campaign
  - Land-use regression (LUR) model
    - Estimate ECAT concentrations at un-sampled locations based on surrounding land and traffic data







Traffic-Related Air Pollution (TRAP)

- Ambient air sampling campaign (2001-2006) at 27 sampling sites
  - Elemental carbon attributable to traffic (ECAT)
    - 24-hour concentrations ($\mu g/m^3$) averaged over 5-year sampling campaign
  - Land-use regression (LUR) model
    - Estimate ECAT concentrations at un-sampled locations based on surrounding land and traffic data

- Estimate ECAT ($\mu g/m^3$) exposure for:
  - Early life (birth record address)
  - Average childhood (time-weighted average of all home addresses from birth - age 12)
  - Current (current home address)

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Air Pollution and Mental Health

- Evidence of air pollution associated with mental health outcomes in adults
  - ↑ Suicide
  - ↑ ED visits for depression / anxiety
- …but first onset is typically in childhood or adolescence
  - Prevalence of major depressive disorder in childhood is 35%
  - Prevalence of anxiety disorders in childhood has increased to > 40%
- Internalizing behaviors
  - Difficult to detect and undertreated
  - Lifelong implications
    - Substance abuse, suicide risk, recurrent unemployment

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Is Childhood Exposure to TRAP Associated with Depression and Anxiety at Age 12 y?

Parent Report

- Behavioral Assessment System for Children (BASC-2)
    - Depression
    - Anxiety
  - Mean = 50, SD = 10
  - ↑ score = more problems

BASC Subscale	n	Mean	SD
Depression	344	49.9	10.2
Anxiety	344	52.1	12.0

r = 0.35

r = 0.24

Child Report

- Child Depression Inventory II Short Form (CDI-II)
- Spence Children's Anxiety Scale (SCAS)
  - Mean = 50, SD = 10
  - ↑ score = more problems

Outcome	n	Mean	SD
Child Depression (CDI-II)	339	52.7	10.2
Child Anxiety (SCAS)	339	44.2	8.2

- Linear regression adjusting for covariates
  - Exposure to TRAP (ECAT) during early life, throughout childhood, and current
  - Parent and child report of depression and anxiety

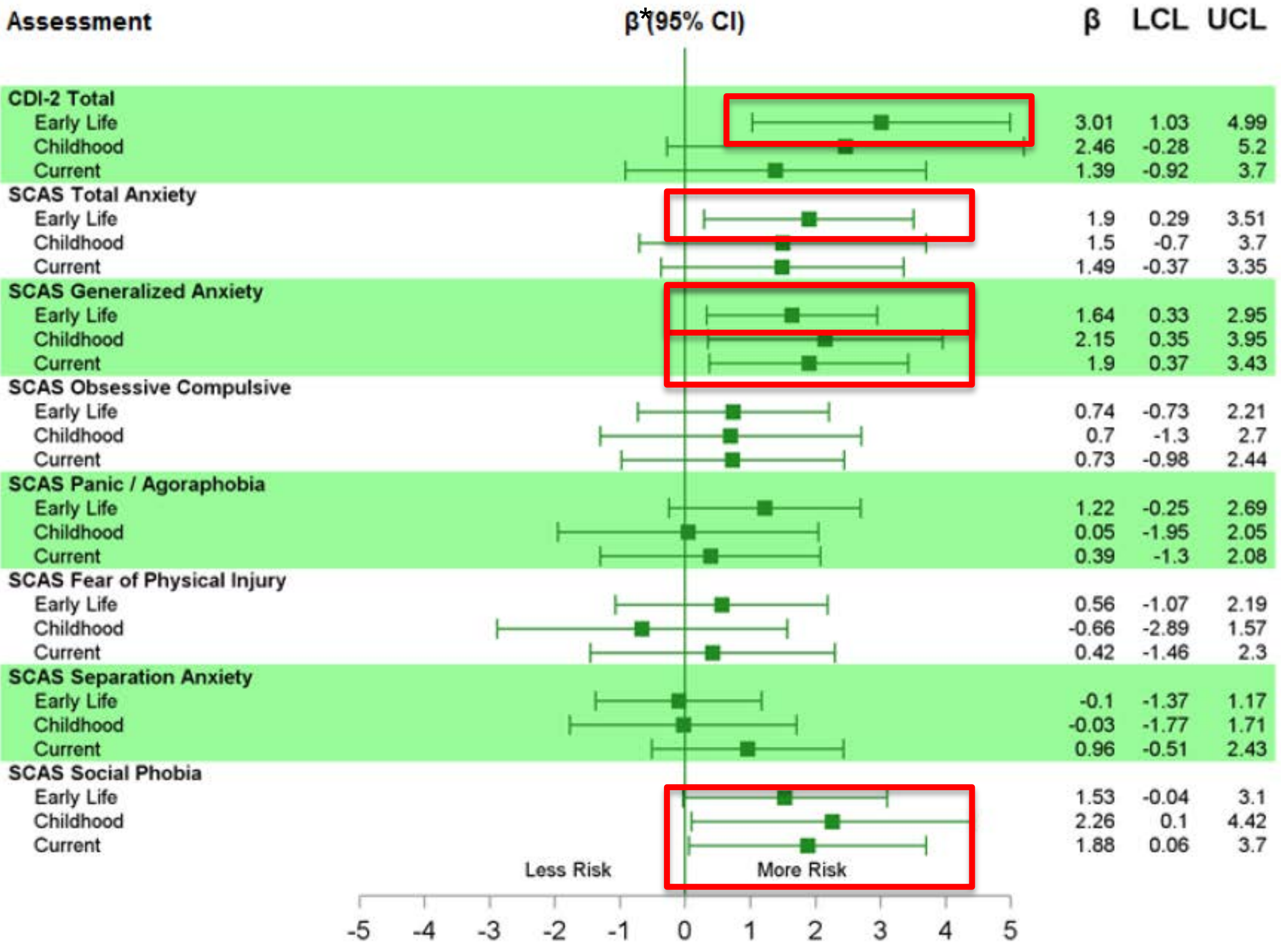
Childhood Exposure to TRAP and Depression and Anxiety at Age 12 y

- No significant associations observed between TRAP exposure and parent-reported (BASC-2) depression and anxiety

Childhood Exposure to TRAP and Depression and Anxiety at Age 12 y

- Early (6m) exposure to TRAP is significantly associated with child-reported depression and anxiety
  - β for 0.25 μg/m^3 ECAT

- Childhood and current exposure to TRAP is significantly associated with generalized anxiety and social phobia

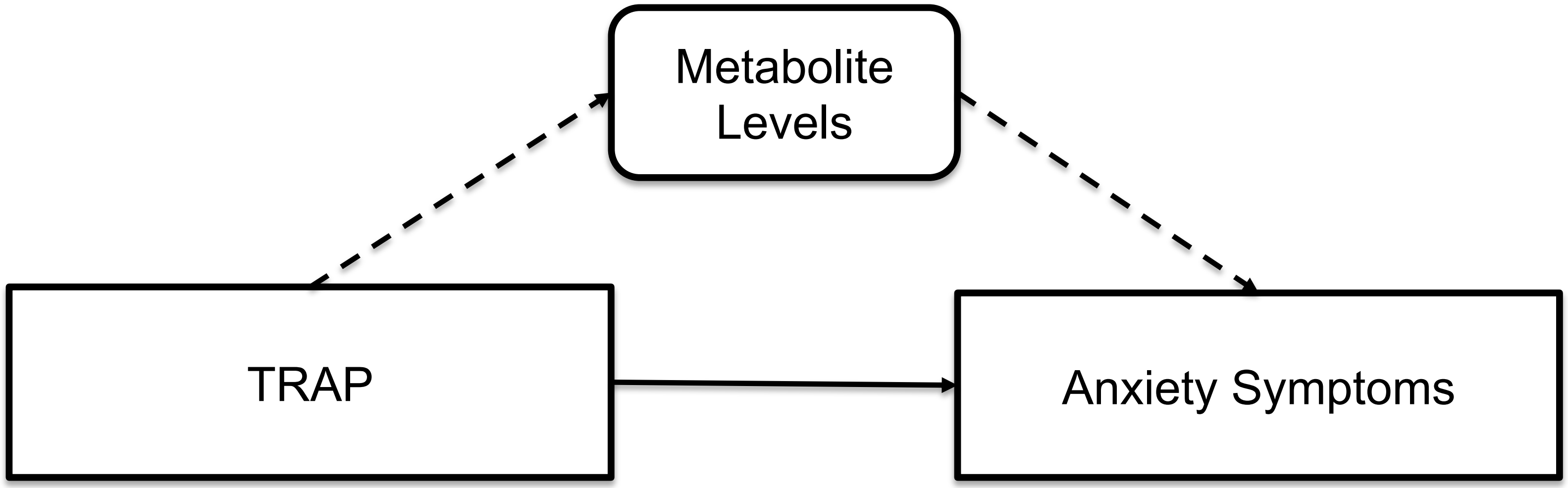


*Adjusted for maternal age at delivery, average household income from birth through 12y, maternal depression, PRQ relational frustration, race, cotinine

Yolton et al. Lifetime exposure to traffic-related air pollution and symptoms of depression and anxiety at age 12 years. *Environmental Research.* 2019;173:199-206.

Role of Brain Metabolism in Child Anxiety

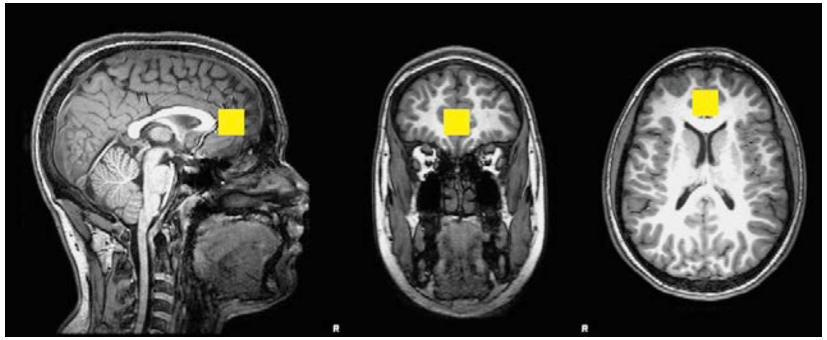
- Magnetic Resonance Spectroscopy
  - Insight into brain metabolism occurring with normal childhood maturation and illness
  - Detect perturbations in brain metabolism when anatomical imaging (MRI) reveals no macroscopic abnormalities

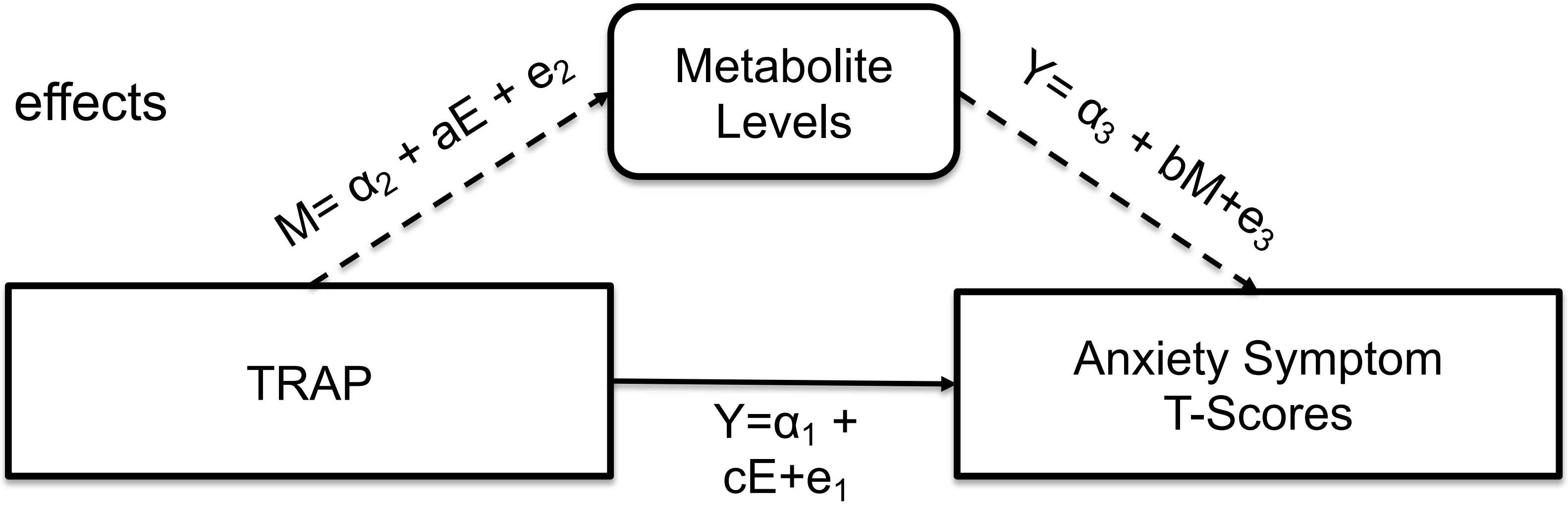


Methods: Imaging and Spectroscopy

- MRI sub-study (n = 145) with high / low TRAP at birth
  - MRS Acquisition
    - Point Resolved Spectroscopy (PRESS) to localize signal to 2x2x2 cm^3 voxel in anterior cingulate cortex
      - Unique position in the brain with connections to both “emotional” limbic system and the “cognitive” prefrontal cortex

- Mediation analysis
  - Determine indirect and total effects



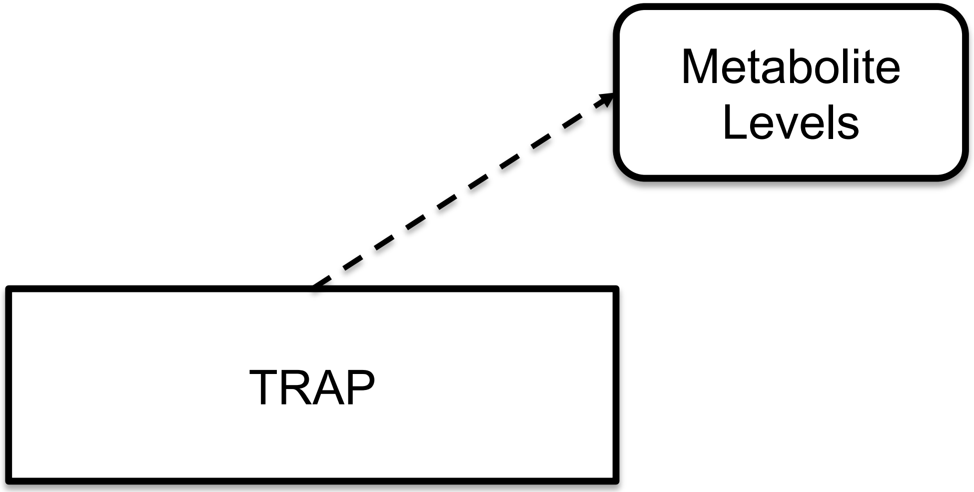


TRAP and Brain Metabolite Levels

- No evidence that early-life exposures are associated with differences in brain metabolite levels

Average TRAP Exposure in the Previous 12 Months

Metabolite	β ECAT[B]	95% CI	P-value
mI	**0.26**	**0.01, 0.51**	**0.04**
NAA	0.24	-0.13, 0.61	0.22
Cr	0.09	-0.15, 0.32	0.47
Cho	0.04	-0.02, 0.11	0.20
Glu	**0.32**	**0.03, 0.61**	**0.03**
Glx	0.52	-0.08, 1.11	0.08
GSH	0.07	-0.08, 0.21	0.38



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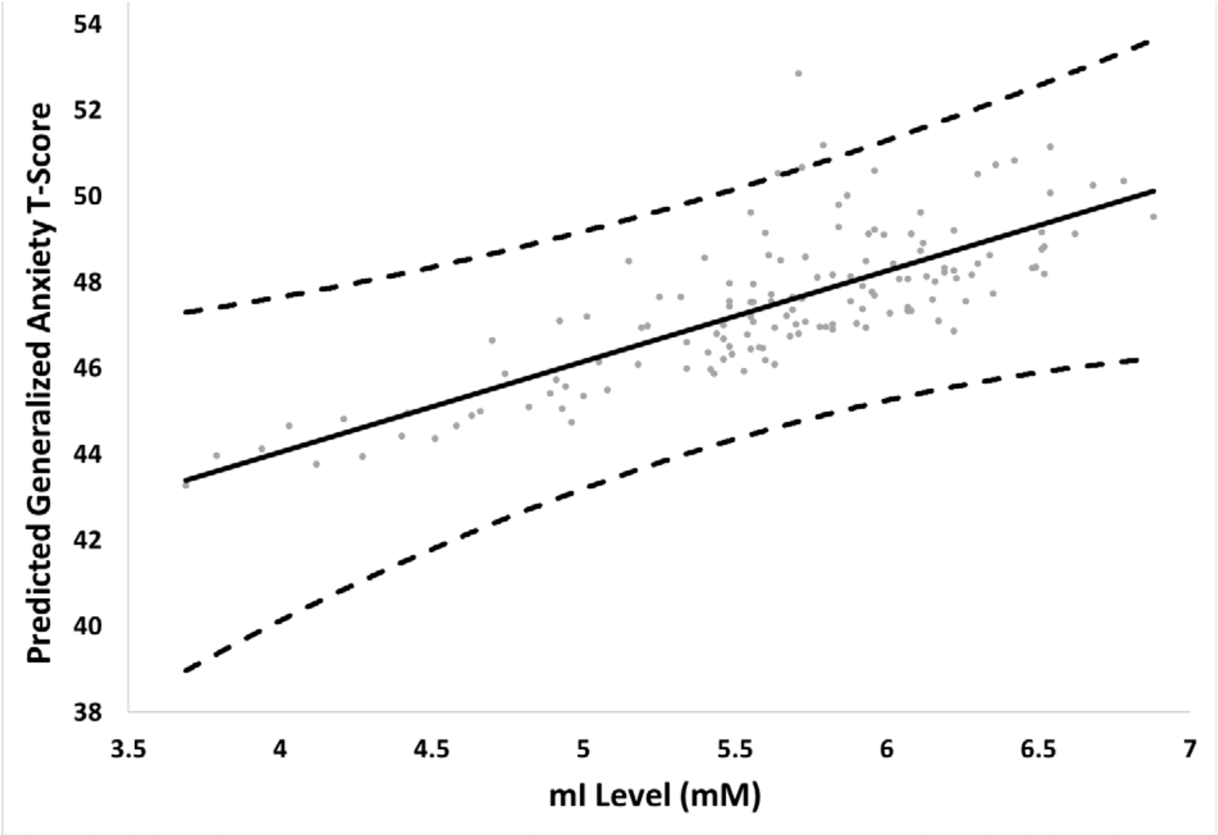
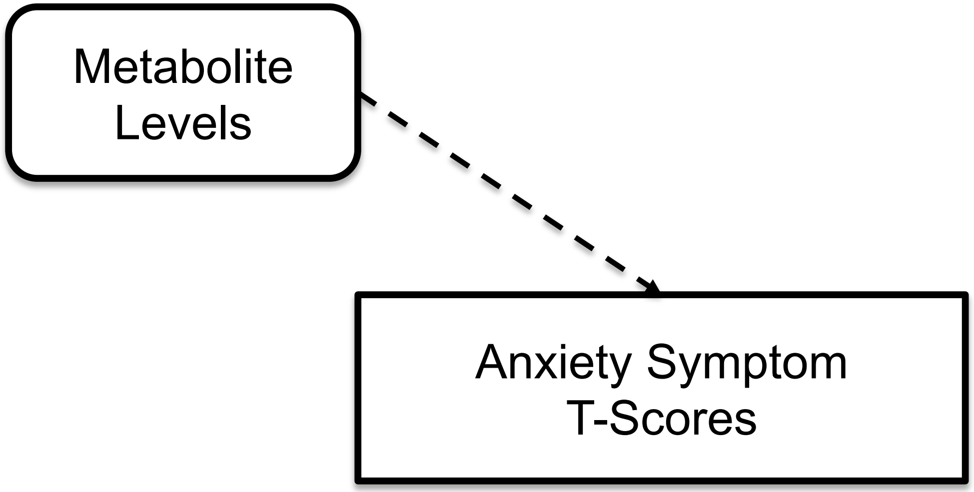
Brain Metabolites and Anxiety



SCAS Outcome	β mI	95% CI	P-value
Generalized Anxiety	2.89	0.94, 4.83	**0.004**
Total Anxiety	3.14	0.85, 5.43	**0.007**
Social Phobia	2.52	0.34, 4.72	**0.02**



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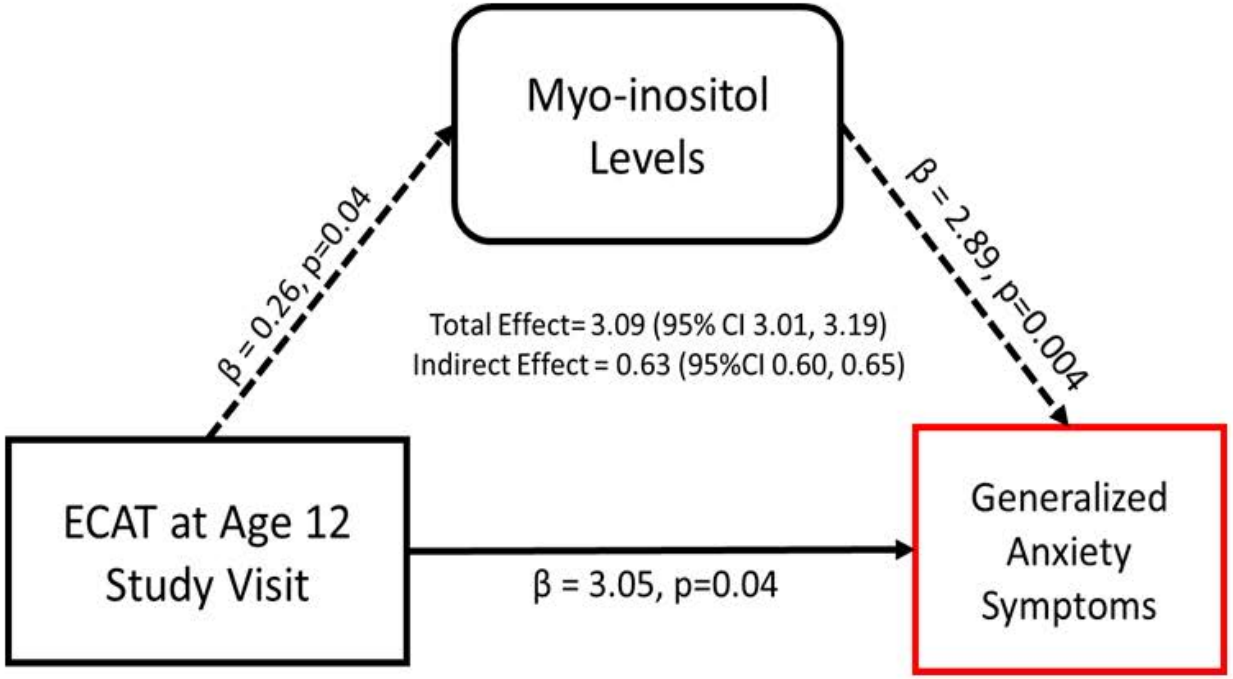
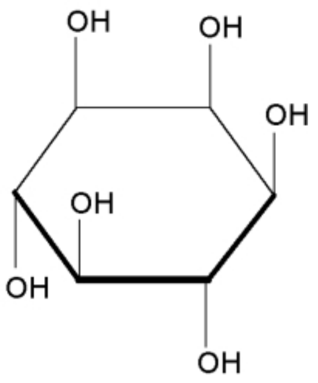
Evidence of mediation?

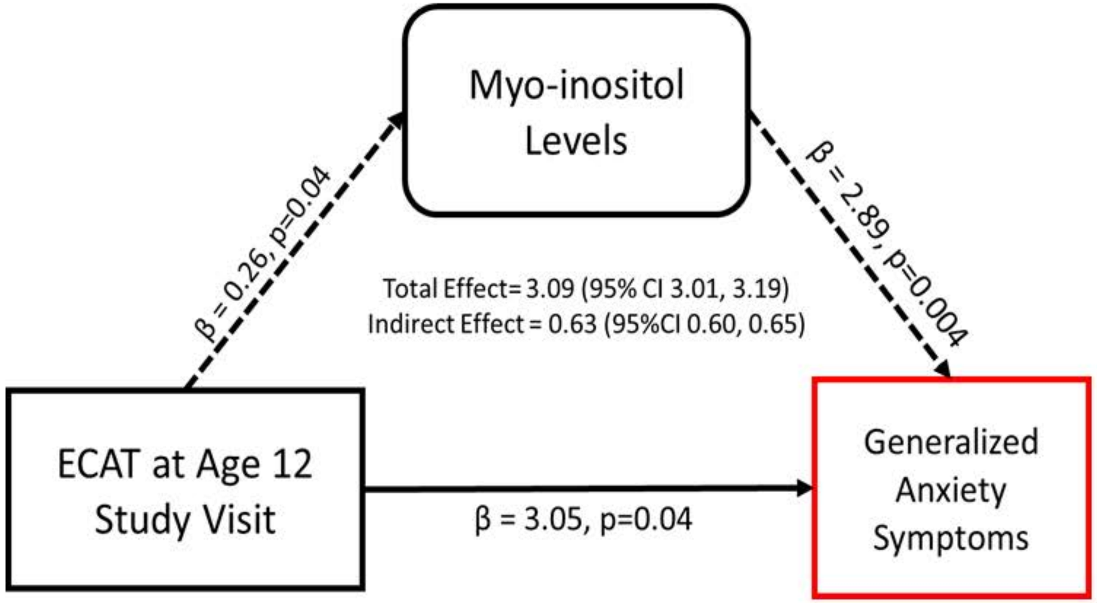


- 20% of total effect mediated by myo-inositol

Brunst et al. Myo-inositol mediates the effects of traffic-related air pollution on generalized anxiety symptoms at age 12 years. *Environmental Research.* 2019;175:71-78

Myo-inositol





- 20% of total effect mediated by myo-inositol

- Myo-inositol
  - Important for many brain processes
  - Increased myo-inositol observed in diseases with
    - Marked astrocytic gliosis (response to CNS damage)
    - Microglial activation (mediated inflammatory response)
    - Brain inflammation
  - Transient nature of myo-inositol
    - Concentrations reflect active processes
    - Other metabolites (such as NAA, Cr, and Cho) reflect structural nature of neural systems

Constituents deposit within ACC | **Increased myo-inositol** | **Generalized Anxiety**

Air Pollution and Brain Structure

- Limited number of studies have evaluated brain structure in childhood related to TRAP
  - Herting et al. 2019 review →n = 6 studies
- 3T Achieva scanner (Philips Medical Systems, Best, Netherlands) equipped with a 32-channel head coil
  - High-resolution, 3-D, anatomical imaging data collected
- 135 CCAAPS participants
  - 59 low ECAT, 76 high ECAT

Reduced Gray Matter Volume and Cortical Thickness Associated With TRAP

- Bilateral, medial region of reduced cortical thickness within the posterior frontal and anterior parietal lobes associated with ECAT exposure
  - Primary motor cortex and sensory areas
  - Voluntary movements and integrating somatosensory information including touch
- Reduced gray matter volume
  - Primarily in the cerebellum
  - Involved with regulating motor function, cognition, and emotion
- Combination of ↓ cortical thickness within the precentral gyrus and ↓ cerebellar volume suggests TRAP may impact motor function

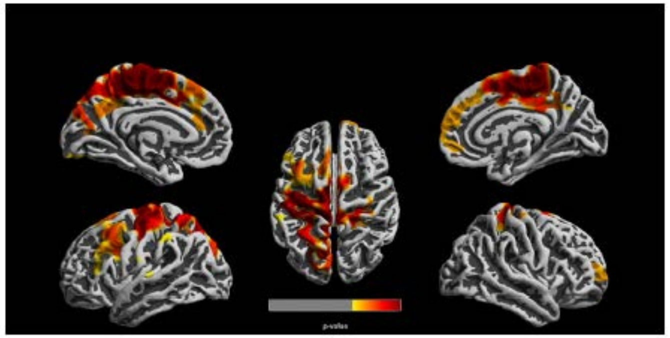


Fig 1. Statistically significant clusters using threshold free cluster enhancement. Clusters represent reduced cortical thickness in the high ECAT group compared to the low ECAT group. Clusters were corrected for multiple comparisons using a familywise error rate of $p \leq 0.05$.

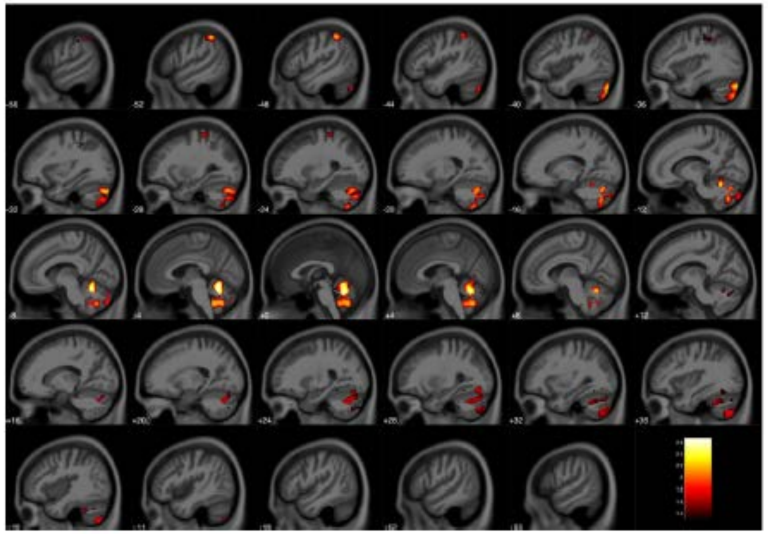


Fig 2. Reduced gray matter volume in the high ECAT group compared to the low ECAT group. Clusters were corrected for multiple comparisons using threshold free cluster enhancement with a familywise error rate of $p \leq 0.05$. Color bar represents –log(p) value.

Beckwith et al. Reduced gray matter volume and cortical thickness associated with traffic-related air pollution in a longitudinally studied pediatric cohort. PLoS One. 2020;15(1):e0228092.

Acute Exposure to Air Pollution and Mental Health in Children

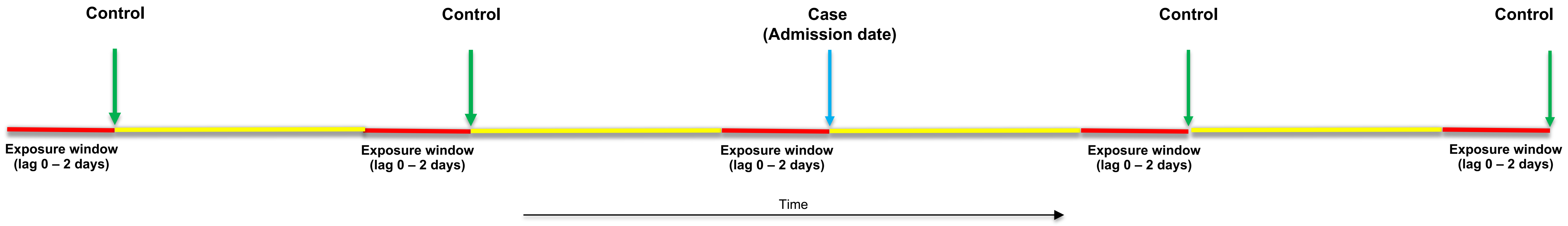
- Evidence of acute $PM_{2.5}$ exposure and acute mental health outcomes in adults
  - Exacerbations of psychiatric disorders linked to inflammation and microglia activation
  - Limited evidence of acute $PM_{2.5}$ and mental health outcomes in children

- Objective: Investigate the relationship between short-term exposure to $PM_{2.5}$ and the risk for pediatric psychiatric emergency department (ED) visits

- Time-stratified case-crossover study design
  - Cases: Cincinnati Children's Hospital ED visits (2011-2015) identified by ICD-10 codes
  - Date of ED visit and home addresses extracted from EHR and geocoded

Acute Exposure to Air Pollution and Mental Health in Children

- Time-stratified case-crossover design
  - Appropriate to examine acute effects of transient exposures
  - Removes confounding from time-invariant measured and unmeasured confounders
  - Control: Prior and post exposure history of cases
    - Match control days on day of week, month, and year
    - Model-based adjustment for temporal confounders including temperature, humidity, and holidays



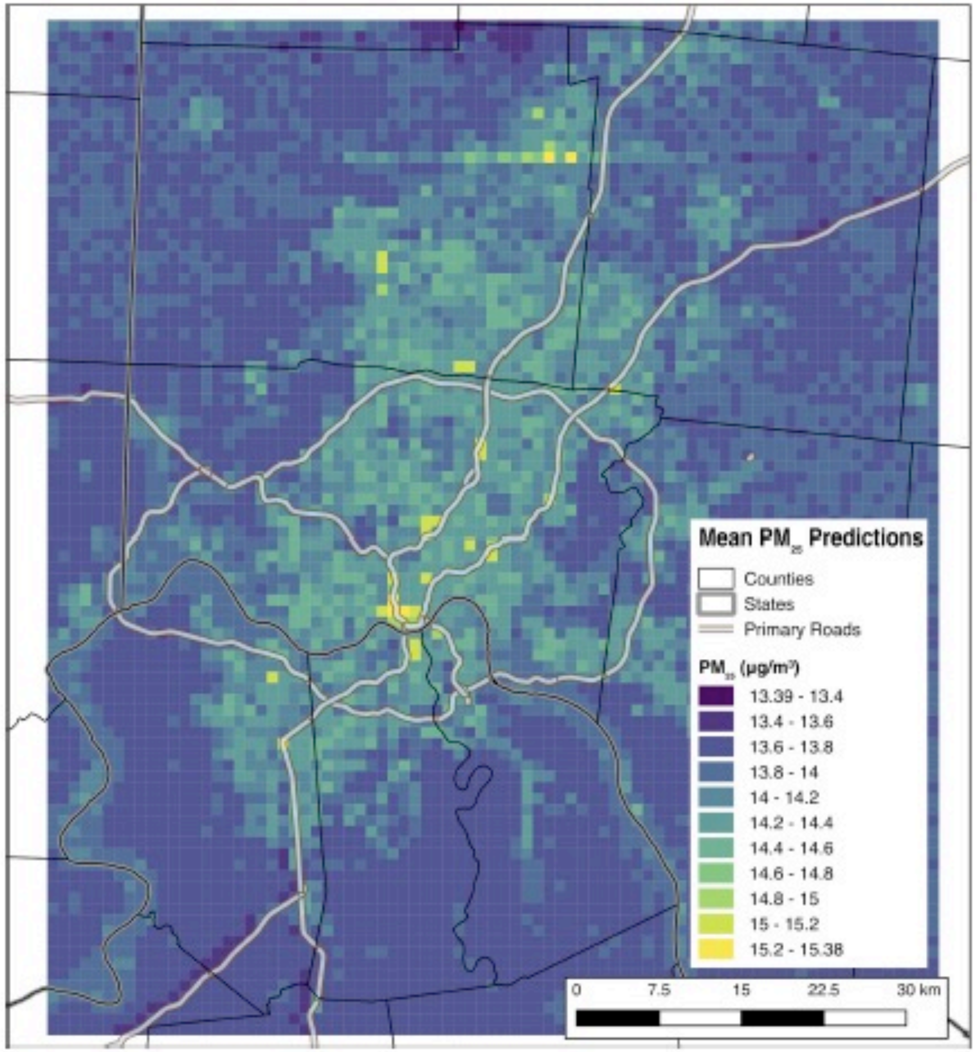
Spatiotemporal $PM_{2.5}$ Model

- Daily concentrations of $PM_{2.5}$ estimated at residential locations on dates specific to cases and controls
- Satellite-based measures of aerosol optical depth
- Meteorological measurements, land use data, roadways, greenspace, grid indicators, day, year
- Calibrated with ground-based $PM_{2.5}$ monitoring data using a random forest model
  - EPA AQS sites (n = 24) + CCAAPS sites (n = 28)
    - 26,369 $PM_{2.5}$ measurements at 52 locations on 4,530 days
  - Cross validated MAE of 0.95 μg/m^3 and R^2 of 0.91
- http://colebrokamp-dropbox.s3.amazonaws.com/Hamilton_June_2010_PM25.gif

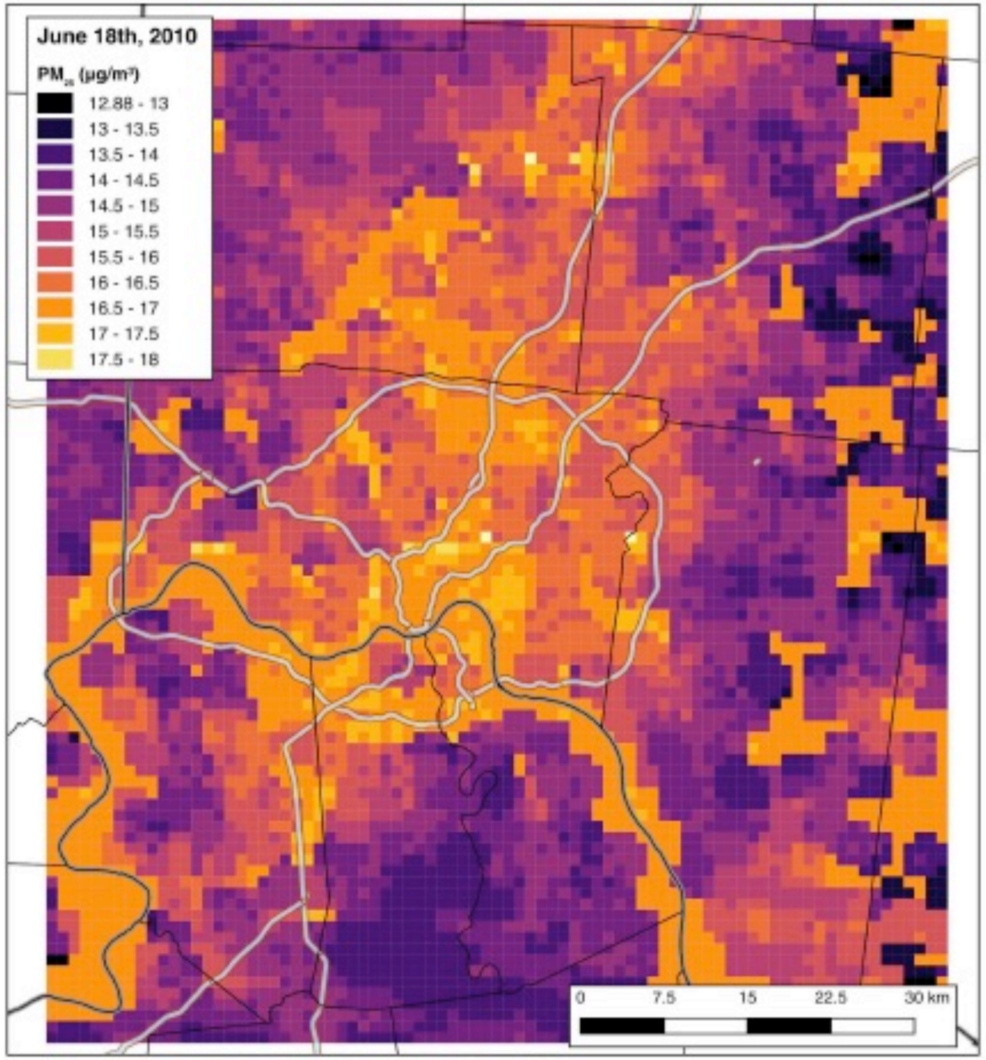
Brokamp C et al. Predicting Daily Urban Fine Particulate Matter Concentrations Using Random Forest. *Environ Sci Technol.* 2018;52(7):4173-79.

Visualizing Model Predictions

Daily $PM_{2.5}$ predictions at each grid cell averaged over 2000 - 2015.



Model $PM_{2.5}$ predictions for June 18th, 2010.



A Section 508–conformant HTML version of this article
is available at https://doi.org/10.1289/EHP4815.

Pediatric Psychiatric Emergency Department Utilization and Fine Particulate Matter: A Case-Crossover Study

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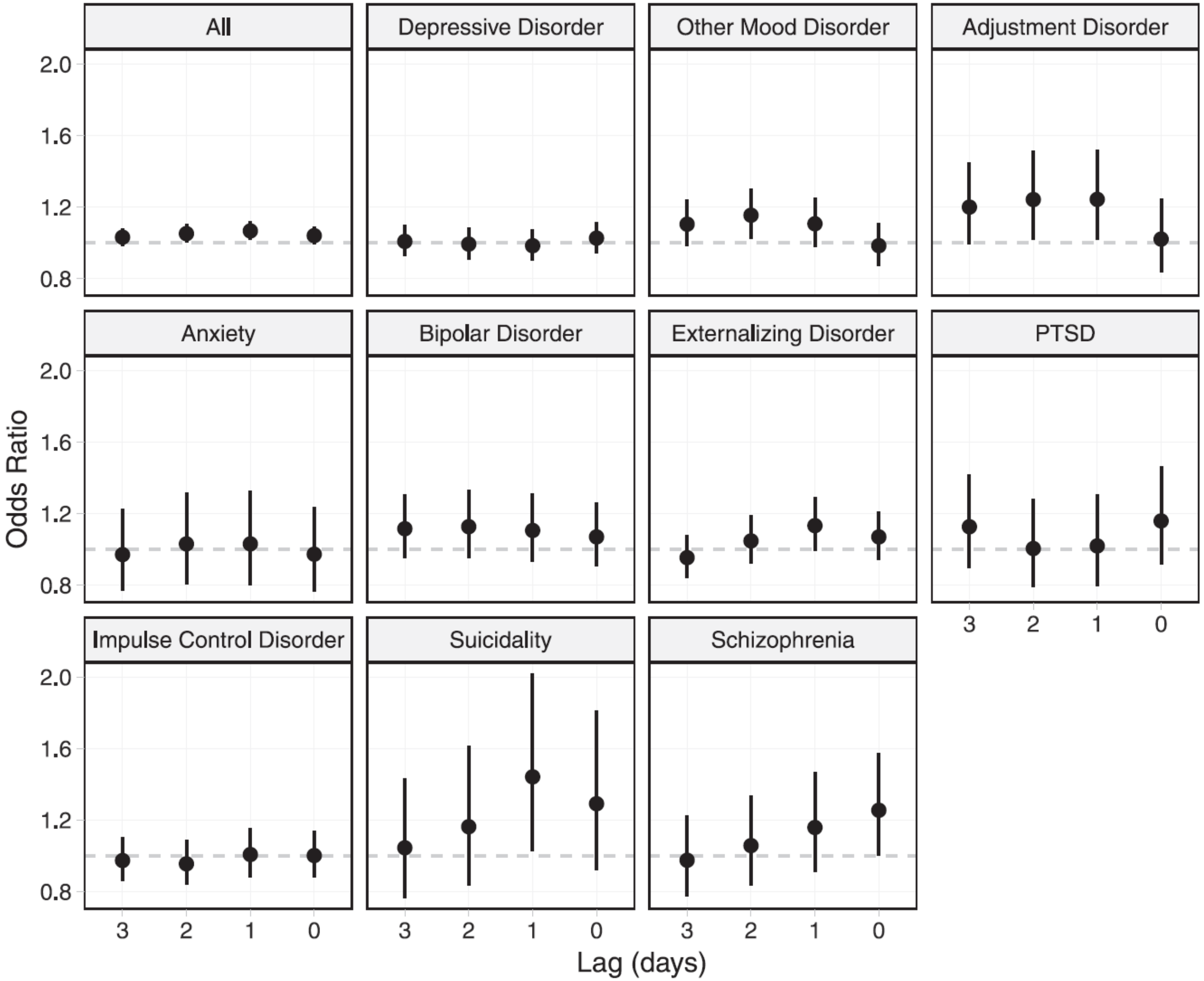
[2]University of Cincinnati; Cincinnati, Ohio, USA

Table 1. Demographic summary information on pediatric psychiatric emergency department (ED) visits collected in Cincinnati, Ohio, between 2011 and 2015 and able to be geocoded within Hamilton County.

Psychiatric ED visit category	*n*	Age (y) [median (25th, 75th %ile)]	Female [*n* (%)]	African American [*n* (%)]	Public insurance [*n* (%)]	High community deprivation [*n* (%)]
Overall	13,176	14.4 (11.7, 16.1)	6,643 (50)	5,756 (44)	8,740 (66)	6,556 (51)
Adjustment disorder	702	13.7 (11.0, 15.8)	366 (52)	322 (46)	442 (63)	346 (49)
Anxiety	486	14.5 (11.9, 16.2)	288 (59)	123 (25)	204 (42)	167 (34)
Bipolar disorder	1,001	15.5 (13.8, 16.8)	535 (53)	405 (40)	744 (73)	537 (53)
Depressive disorder	3,847	15.3 (14.0, 16.5)	2,692 (70)	1,239 (32)	1,989 (51)	1,501 (39)
Developmental disorder	88	13.7 (9.6, 15.7)	9 (10)	27 (31)	48 (55)	33 (38)
Externalizing disorder	1,850	11.7 (8.4, 14.5)	572 (31)	1,019 (55)	1,440 (78)	1,143 (62)
Impulse control disorder	1,755	11.6 (8.8, 14.4)	453 (25)	900 (50)	1,425 (80)	992 (56)
Other mood disorder	1,903	14.4 (12.2, 16.0)	996 (52)	959 (50)	1,400 (73)	1,155 (60)
Personality disorder	142	12.0 (8.2, 14.8)	38 (27)	66 (47)	103 (73)	74 (52)
PTSD	519	14.0 (10.7, 15.8)	354 (67)	269 (51)	412 (78)	317 (60)
Schizophrenia	500	15.5 (13.0, 16.8)	175 (35)	327 (64)	378 (75)	284 (56)
Suicidality	275	15.0 (12.8, 16.6)	163 (59)	100 (36)	155 (56)	114 (42)

Note: In total, 13,176 unique ED visits were contributed by 6,812 unique individuals. Each outcome was classified using primary diagnosis ICD-10 codes as indicated in Table S1. Age, sex, self-reported race, and public (i.e., government-provided) insurance information was extracted from the electronic health record. Community deprivation was derived using a principal components analysis of six census tract–level American community survey variables. High community deprivation was defined as greater than the median of all census tracts in Hamilton County. %ile, Percentile; ICD-10, *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision*; PTSD, post-traumatic stress disorder.

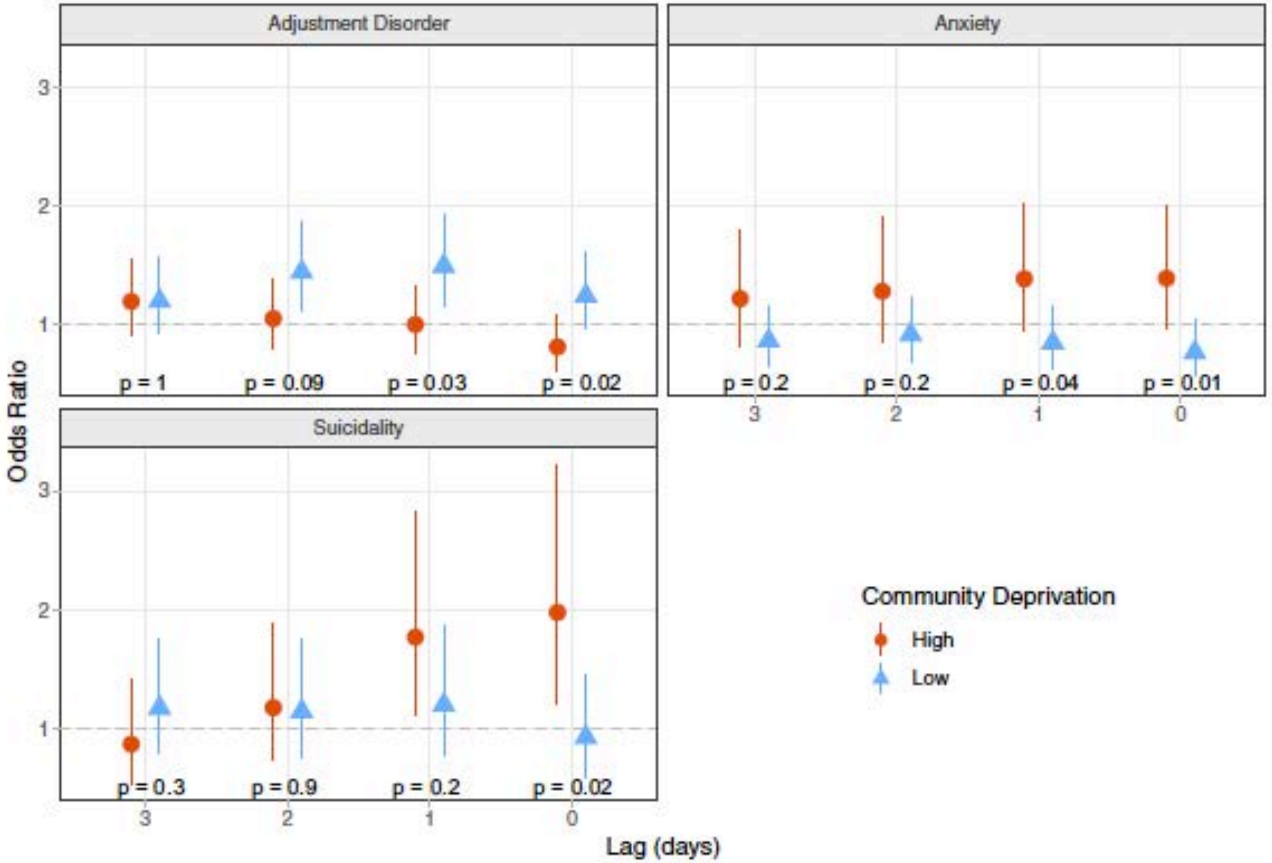
Odds Ratio* for 10 μg/m^3 increase in $PM_{2.5}$



* Adjusted for temperature, humidity, and holidays

Effect Modification by Community Deprivation

- Associations were modified by community deprivation
  - Higher community deprivation increased risk for suicidality and anxiety
  - Lower community deprivation increased risk for adjustment disorders



Summary and Future Directions

- **Summary**
  - Exposure to air pollution during childhood may disrupt normal brain development and manifest in multiple neurodevelopmental domains
  - Data from CCAAPS suggests childhood exposure to TRAP is associated with internalizing disorders in adolescence
  - Recent short-term $PM_{2.5}$ exposure is associated with may cause acute mental health outcomes
    - Brain metabolites and inflammation may play a role

- **Future Directions**
  - Analyses of additional neurodevelopmental domains in CCAAPS
  - Examine potential modifiers of air pollution – neurodevelopmental outcomes including greenspace, noise, heat, community deprivation, and other chemical and non-chemical stressors
  - Identify composition of $PM_{2.5}$ most relevant to neurodevelopmental outcomes

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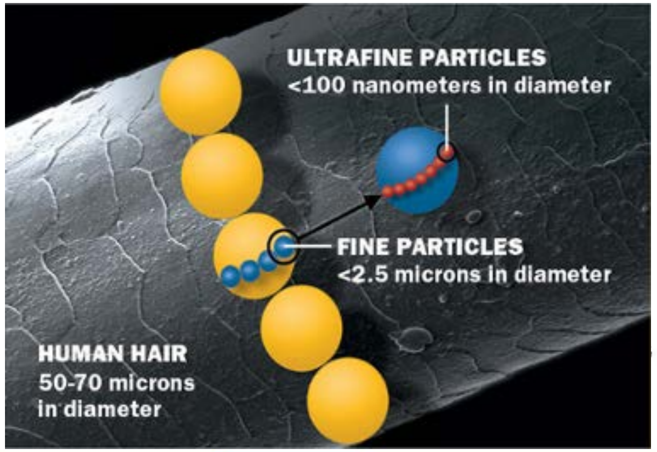
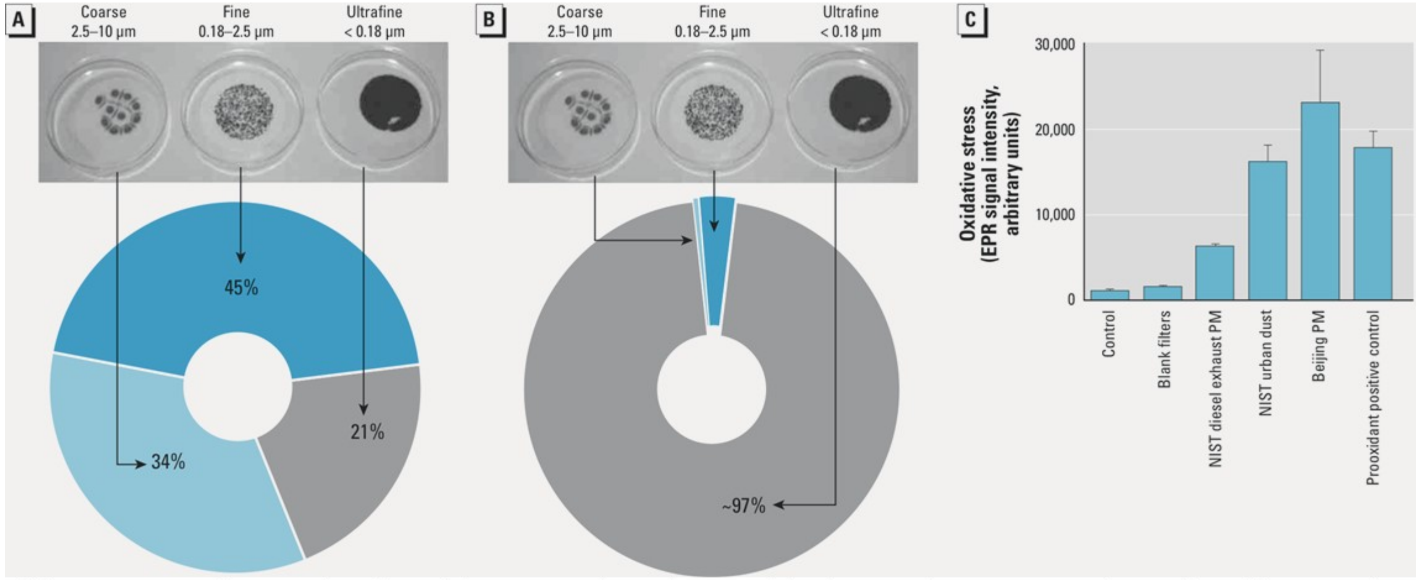
Ultrafine Particles

- Natural sources: biological agents, geological processes, and atmospheric transformations
- Anthropogenic sources: high temperature processes (e.g. welding, smelting), combustion (mobile sources, cooking, heating), and industrial emissions
- Evidence from toxicological studies suggest that UFPs:
  - Play a significant role in PM toxicity due to their size and ability to absorb toxic chemicals (e.g. PAHs, organic compounds, metals) onto large surface areas
    - Generate reactive oxygen species (ROS) and oxidative stress
    - Translocate to the brain and other organs
- Limited epidemiologic studies focused on UFPs
  - Challenges in exposure characterization



Challenges in UFP Exposure Assessment

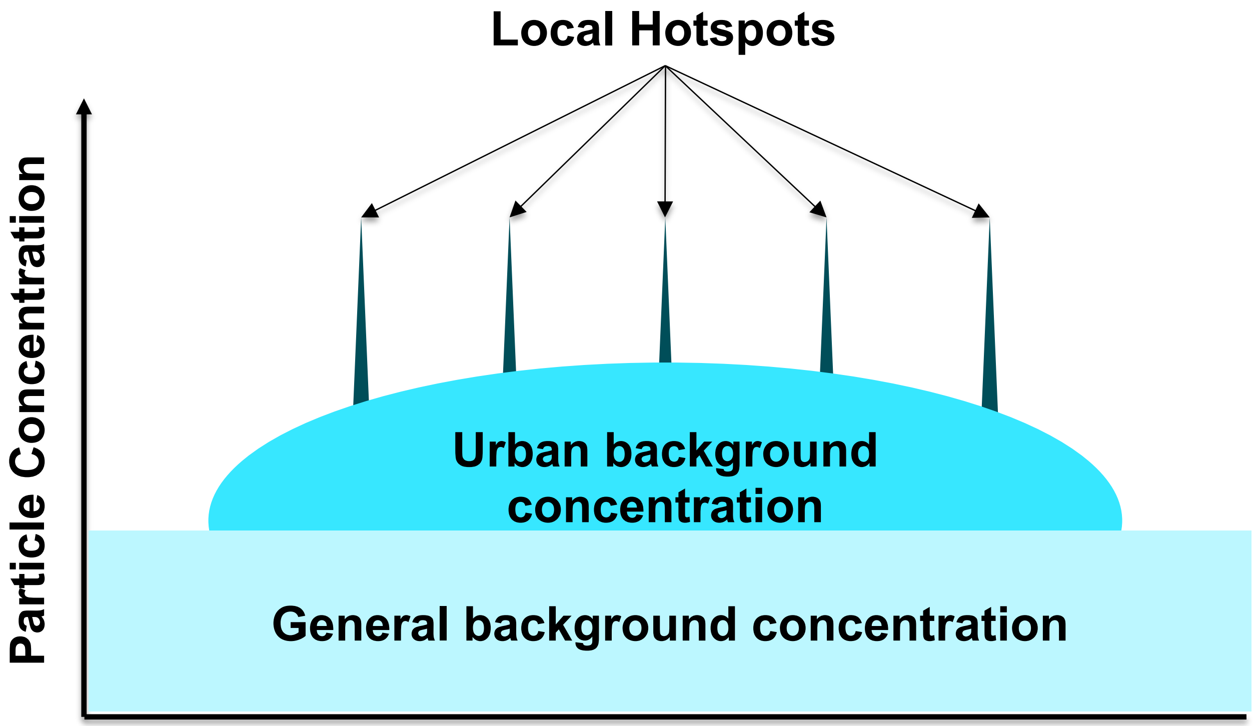
- UFPs have negligible mass
  - Do not contribute to PM mass concentrations
    - Health effects of PM_{10} and $PM_{2.5}$ based on PM mass
  - UFPs require alternative exposure metrics
    - Particle number, surface area



(*A*) Representative filter samples collected showing contribution by mass of the three size fractions averaged over 3 days. (*B*) Estimated contribution of each size fraction collected on filters by particle number. (*C*) Oxidative potential of the collected Beijing PM (1 mg/mL) using EPR to assess oxygen-centered free radical generation, compared with NIST diesel exhaust PM (10 µg/mL) and urban dust (1 mg/mL) and the prooxidant positive control (pyrogallol 100 µM) as described previously (Miller et al. 2009). Data are mean ± SD (*n*= 2–4).

Challenges in UFP Exposure Assessment

- Personal exposure frequently exceeds monitored data
  - Personal activities
  - Localized (‘hot spots’)
  - Indoor exposures
  - Children → ↑ exposure



Individual-level Exposure Assessment for Epidemiologic Studies

Required data
Complexity
Effort
Accuracy

Proximity Models | **Land-Use Regression** | **Personal Monitoring**

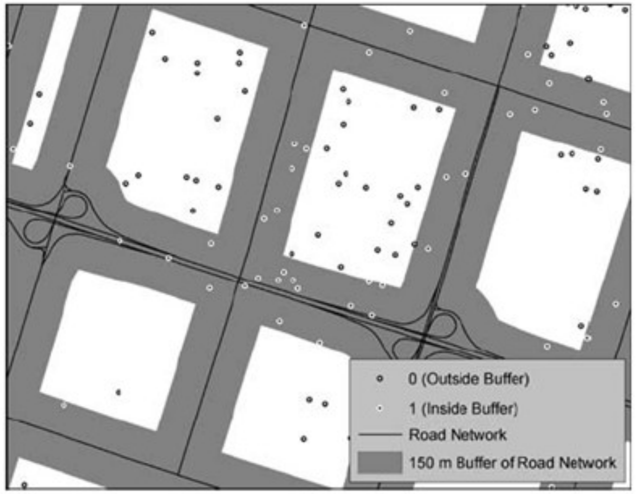


Figure 1. Example of binary classification within a buffering scheme for proximity models.

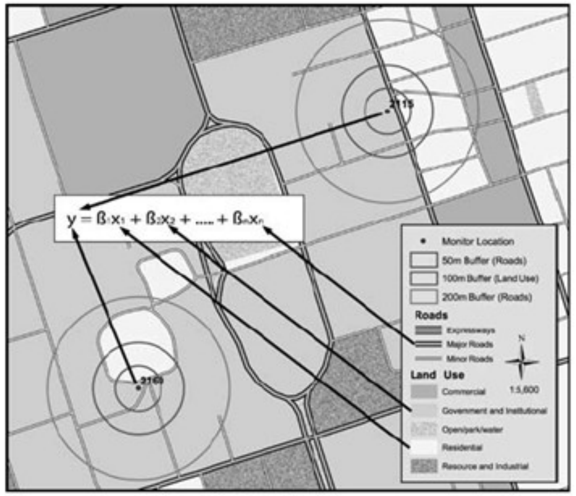
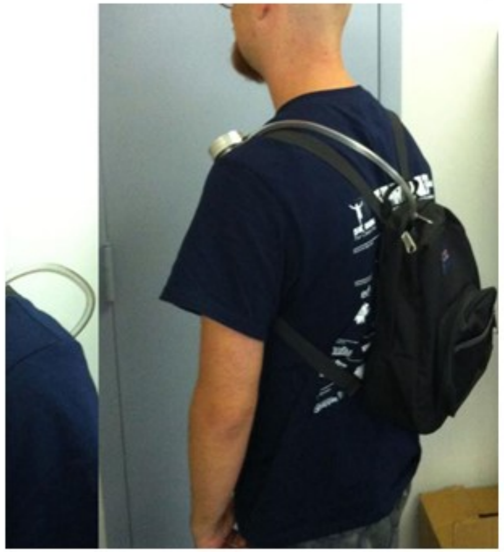


Figure 3. Elements of a land use regression model showing monitoring locations for NO_2 as the response variable and land use characteristics within buffers as the predictor variables.



Jerrett et al. A review and evaluation of intraurban air pollution exposure models. *J Exposure Science and Environmental Epidemiology*. 2005;15:185-205.

Personal UFP Sampling Instruments

Science of the Total Environment 603–604 (2017) 793–806

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

Review of measurement techniques and methods for assessing personal exposure to airborne nanomaterials in workplaces

Christof Asbach [a,*], Carla Alexander [b], Simon Clavaguera [c], Dirk Dahmann [d], Hélène Dozol [c], Bertrand Faure [c], Martin Fierz [e], Luca Fontana [f], Ivo Iavicoli [f,g], Heinz Kaminski [a], Laura MacCalman [b], Asmus Meyer-Plath [h], Barbara Simonow [h], Martie van Tongeren [b], Ana Maria Todea [a]

INSTRUMENT ►	MINIDISC DISCMINI	NANOTRACER (Fast mode)	NANOTRACER (Advanced mode)	PARTECTOR	PUFP C100	PUFP C200	MICROAETH AE51
SIZE (H x W x D) (cm x cm x cm)	18 x 9 x 4.5	16.5 x 9.5 x 3		13.4 x 7.8 x 2.9	19 x 11 x 7	13 x 10 x 7	11.7 x 6.6 x 3.8
WEIGHT (g)	670	750		400	1,000	750	280
PARTICLE SIZE RANGE (nm)	10–300	Fast mode 20–120	Advanced mode 10–300	10–10,000	≥ 4.5		–
CONCENTRATION RANGE	10^3–10^6 #/cm³	0–10^6 #/cm³		0–2*10^4 µm²/cm³	0–2*10^5 #/cm³		0–1 mg BC/m³
METRIC	NC/d_p/LDSA	NC	NC/d_p/LDSA	LDSA	NC		Black Carbon concentration
ACCURACY	± 30%	± 1,500 cm^{-3}		± 20%	± 10%		±1 µg BC/m³
SAMPLE FLOW (lpm)	1	0.3–0.4		0.5	0.3		0.05/0.1/0.15/0.2
TIME RESOLUTION (s)	1	3	16	1	1		1/10/30/60/300
BATTERY LIFE TIME (h)	6–8	7		15	3.3– 6		6–24

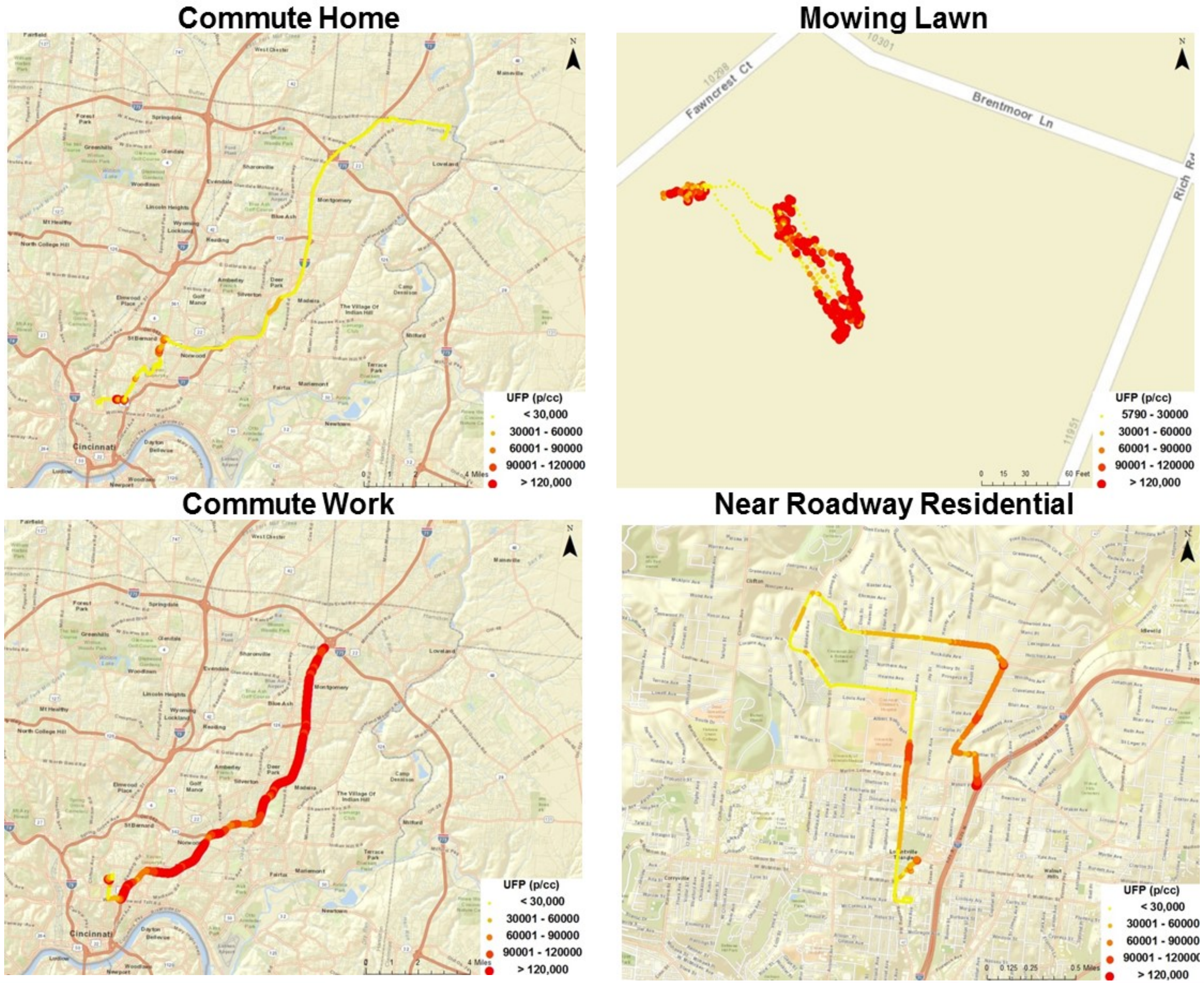
PUFP C200 Technical Specifications

- < 1 s response time
- Concentration range: 0 – 2 x 10^5 particles/cm^3
- Particle size range: > 6 nm (D_{50})
- Sustainability: > 4 g
- Weight: 0.75 kg (C200), 1 kg (C100)
- Size: 910 cm^3 - 13 cm x 10 cm x 7 cm (C200)
- Built-in GPS
- Data interface: USB or Bluetooth
- Data storage: micro-SD card
- Rechargeable Lithium Polymer battery (~3 hrs @ room temp)
- Validated against reference instruments

TSI P-Trak Model 8525 ~ 5,300 cm^3 | Enmont PUFP C100 1,500 cm^3 | Enmont PUFP C200 910 cm^3 | Samsung Galaxy S4

Cincinnati Children's
changing the outcome together

PUFP Field Testing



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Personal Monitoring Pilot Test

- Objectives
  - Assess the capability of the sensor to provide reliable, accurate, and spatiotemporally resolved measures of exposure to PM1.0 number concentration for asthmatic children
  - Determine the acceptability, usability, and compliance of children and their caregivers

- 20 children ages 9 – 14 with asthma
  - Recruited from 3 Cincinnati Public Schools

- Personal monitoring began in afternoon at school and continued ~3 hours on 2 consecutive days

- 4 'microenvironments' defined based on GPS coordinates
  - School, Transit, Home, and Other

UFPs by Microenvironment

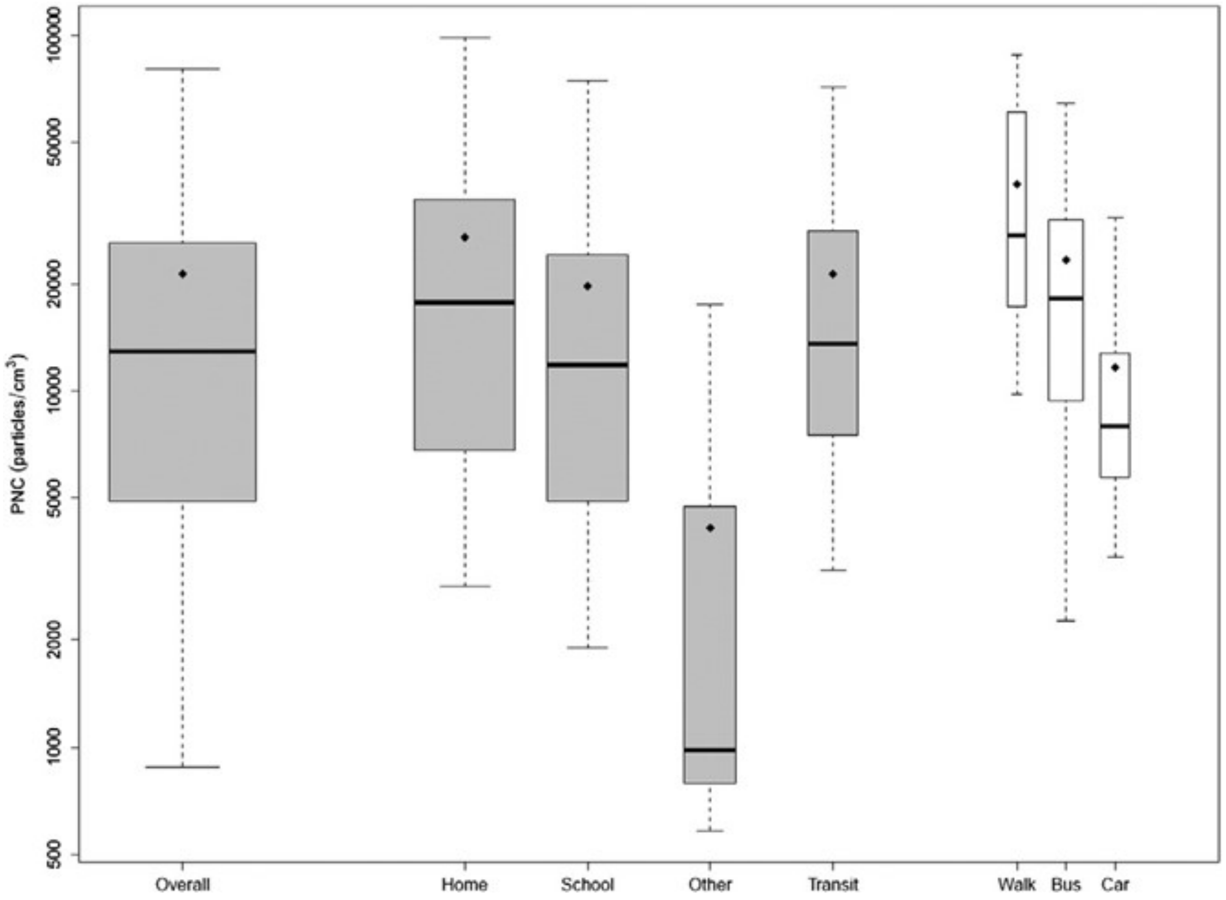

Table 2
Summary of UFP particle number concentration (p/cm^3) by location.

Location	Mean (SD)	5th %-tile	25th %-tile	Median	75th %-tile	95th %-tile
Personal – overall	21,400 (25,100)	900	4900	12,900	26,000	80,200
School	19,800 (22,800)	1900	4900	11,900	24,300	74,600
Home	27,000 (28,300)	2800	6800	17,800	34,500	98,600
Others	4100 (5700)	600	800	1000	4700	17,500
Transit	21,400 (20,600)	3100	7500	13,600	28,200	71,600
Walking	38,100 (26,800)	9800	17,300	27,400	61,000	87,900
School bus	23,400 (20,000)	2300	9400	18,200	30,300	64,500
Car	11,700 (11,000)	3400	5700	8000	12,800	30,700

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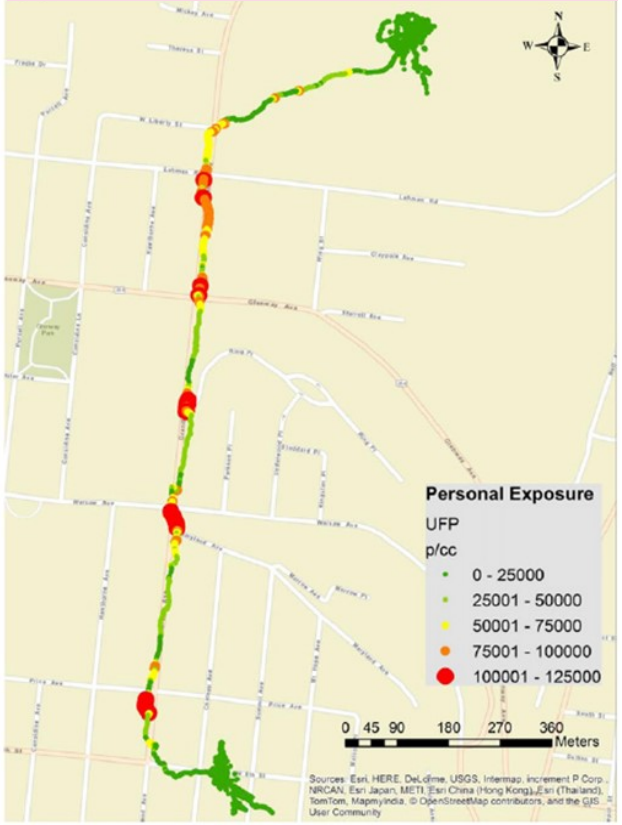
Visualization: Personal UFP Exposure

Participant 1

- School and home in an urban area < 400 m from major road
- Elevated exposure throughout sampling including transit (walking)

Participant 2

- School and home in suburban area > 400 m from major road
- Short-term peak exposures during transit
  - Street intersections



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Ecological Momentary Assessment and Personal Particle Exposure (EcoMAPPE)

- Objective
  - Characterize personal exposure to UFP among adolescents with and without asthma and examine associations with health outcomes
    - 100 participants
    - 7 day sampling periods (x 2)
    - Ecological momentary assessment
    - Additional exposure and health sensors / monitors

MadresGPS
- GPS
- Accelerometer

Ecological Momentary Assessment (EMA)
- Questionnaires
- Reminders
- Photographs

Fitbit Charge 2
- Activity, sleep, heart rate

iButton Logger
- Temperature
- Humidity

Enmont PUFP C200
- GPS
- UFP p/cc

Spirobank Smart
- FEV1, FVC, Peak Flow, FEF_{25-75},

Blood
- Inflammatory markers
- Metabolomics

NEATVIBEwear
- Noise

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Ecological Momentary Assessment and Personal Particle Exposure (EcoMAPPE)

Characteristics of EcoMAPPE Participants (n = 118)

Characteristic	Mean (range) / n (%)
Age	15 (13 - 18)
Sex	
Male	52 (44%)
Female	66 (56%)
Race	
Black / Bi-racial	30 (26%)
White	88 (74%)
Asthmatic	
Yes	50 (42%)
No	68 (58%)
Total Duration of UFP sampling (hrs)	2,190
Maternal Education	
< High School	10 (9%)
Some College	17 (14%)
College / Grad School	83 (70%)
Missing	8 (7%)

MadresGPS
- GPS
- Accelerometer

Ecological Momentary Assessment (EMA)
- Questionnaires
- Reminders
- Photographs

Fitbit Charge 2
- Activity, sleep, heart rate

iButton Logger
- Temperature
- Humidity

Enmont PUFP C200
- GPS
- UFP p/cc

Spirobank Smart
- FEV1, FVC, Peak Flow, $FEF_{25\text{-}75}$,

Blood
- Inflammatory markers
- Metabolomics

NEATVIBEwear
- Noise

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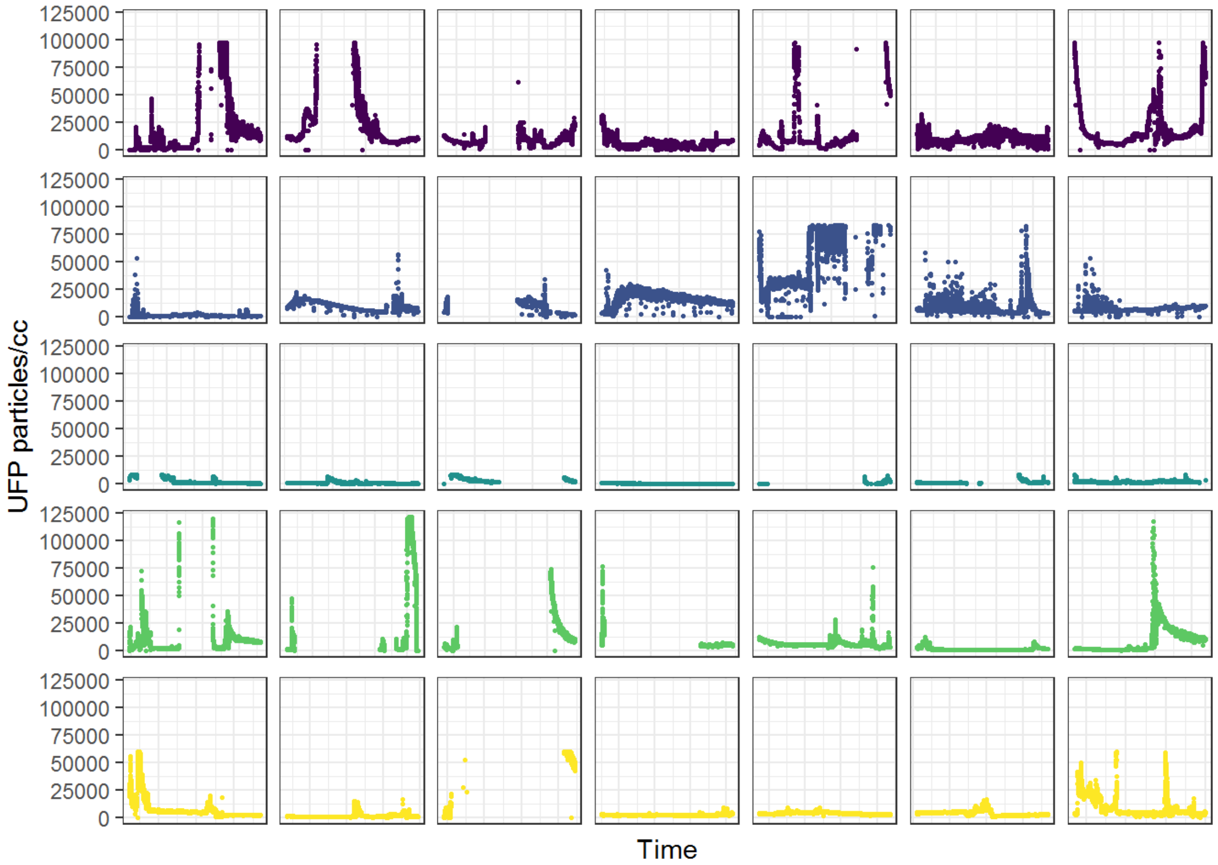
UFP Exposure Results

UFP particle number concentration (p/cc) by microenvironment

Location	Hrs (% total)	Mean	5th %-tile	25th %-tile	Median	75th %-tile	95th %-tile
Overall	2000	21,636	359	1,800	5,010	14,800	94,700
Home	1239 (62%)	19,529	392	1,730	4,830	14,900	99,920
School	60 (3%)	7,219	644	2,310	4,180	8,340	24,400
Transit	158 (8%)	19,360	985	3,639	8,110	18,880	77,900
Other	384 (19%)	7,219	294	1,920	5,730	17,900	119,900
Unknown	160 (8%)	11,421	76	1,000	2,600	7,730	59,440



Reporting Back Individual Results of Personal Air Monitors

- Real-time and geolocated sampling provides in-depth insight regarding specific locations, activities, and times with elevated exposures
  - Fundamentally different than traditional exposure methods using fixed monitoring sites, modeling, or integrated personal monitoring

- Actionable information that is analogous to biological monitoring of chemical exposures
  - More informative than biomonitoring data!
    - Increase awareness of exposure
    - Identify specific locations of elevated exposure
    - Identify specific times and activities associated with elevated exposure
    - Potential to inform behavioral changes to decrease exposure

News | Science Selections

Way to Go

Identifying Routes for Walkers and Cyclists to Avoid Air Pollutants

Exposures to air pollutants may offset a portion of the health benefits of walking and bicycling in cities.[1] However, taking a detour just a block or two away from the busiest streets and roads "can make a big difference in your exposure," says Steve Hankey, an assistant professor at Virginia Polytechnic Institute and State University and coauthor of a new study in *EHP*.[2]

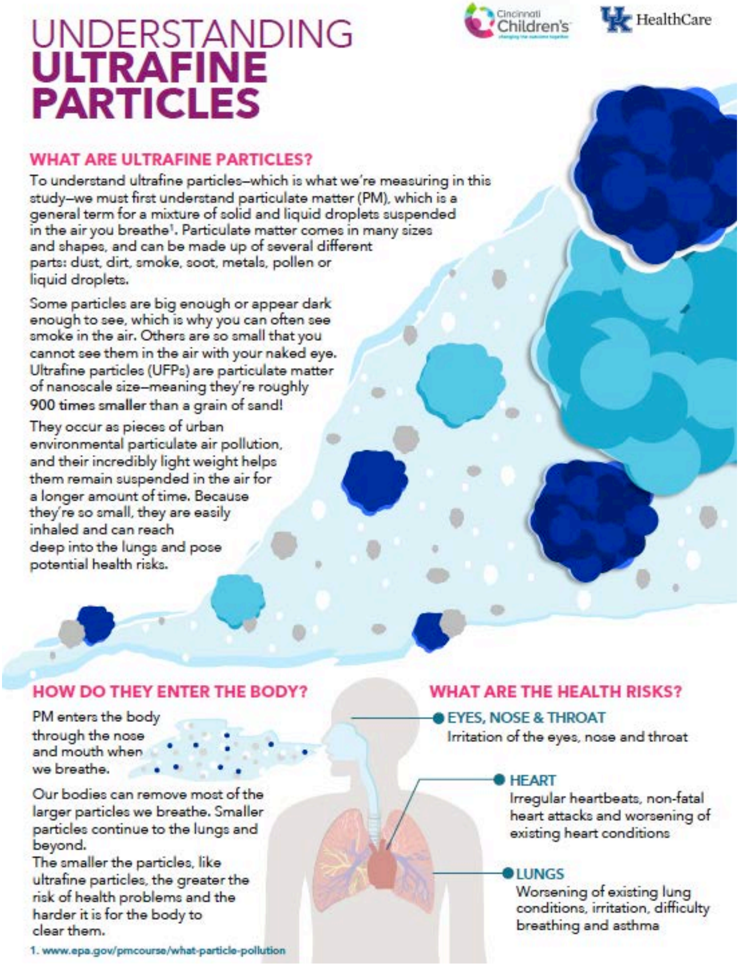
Reporting Back Individual Results of Personal Air Monitors

- Biomonitoring studies
  - Consensus that returning participants biomonitoring results in an understandable and meaningful way is appropriate[1]
    - Ethical, right-to-know
    - Increase knowledge of participants and motivate action
    - Unanticipated benefits
- Studies of air pollution do not typically return exposure assessments
  - Modeling uncertainty
  - Influence of time-activity patterns

1. Ohayon et al. Environmental Research. 2017;153:140-149.

Reporting Back Individual Results of Personal Air Monitors

- Goal: Collaborate with EcoMAPPE participants and caregivers to develop effective report-back strategies for personal air monitors
  - Increase engagement, improve knowledge of environmental health, and motivate changes to decrease exposure



EcoMAPPE Data → Focus Groups → Expert Panel → Focus Groups → Report-back to all Participants → Feedback / Pre-post knowledge assessment

Summary and Future Directions

- **Summary**
  - Successfully integrated multiple data streams to capture exposures, locations, health, and activity
    - Challenge: participant burden, sensor technology (e.g. battery life), data management
  - Multiple environmental sensors offer the potential to disentangle correlated exposures (e.g. noise and UFP)
    - Challenge: sufficient sample size, generalizable study populations

- **Future Directions**
  - EcoMAPPE
    - Health analyses
    - Metabolomic profiles of ultrafine particle exposure
  - Comparison of personal $PM_{2.5}$ and UFP
    - Inhaled dose
    - Health effects
  - Identifying and reducing UFP exposures
    - Develop effective report-back strategies for personal air pollution monitoring

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