Interrelationships Between Urban Green Space, Air Pollution, and Health

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Health Effects 2018 Annual Conference, Chicago, IL
May 1, 2018

Outline

Health effects of greenness

Interrelationships between greenness and air pollution

Impacts of greenness and air pollution on health

Outline

Health effects of greenness

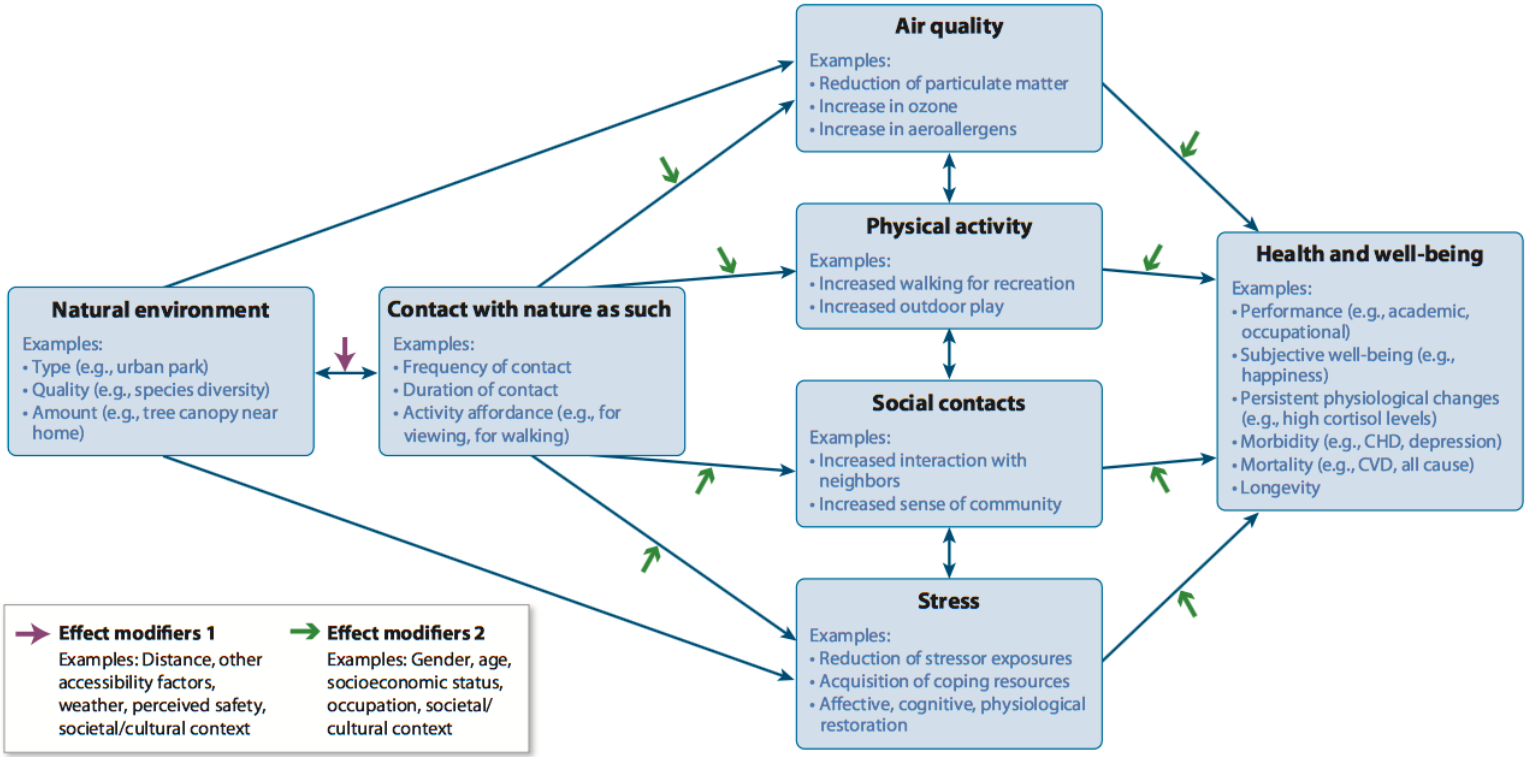
Interrelationships between greenness and air pollution

Impacts of greenness and air pollution on health

Health effects of greenness

- Proposed mechanisms
- Observational studies

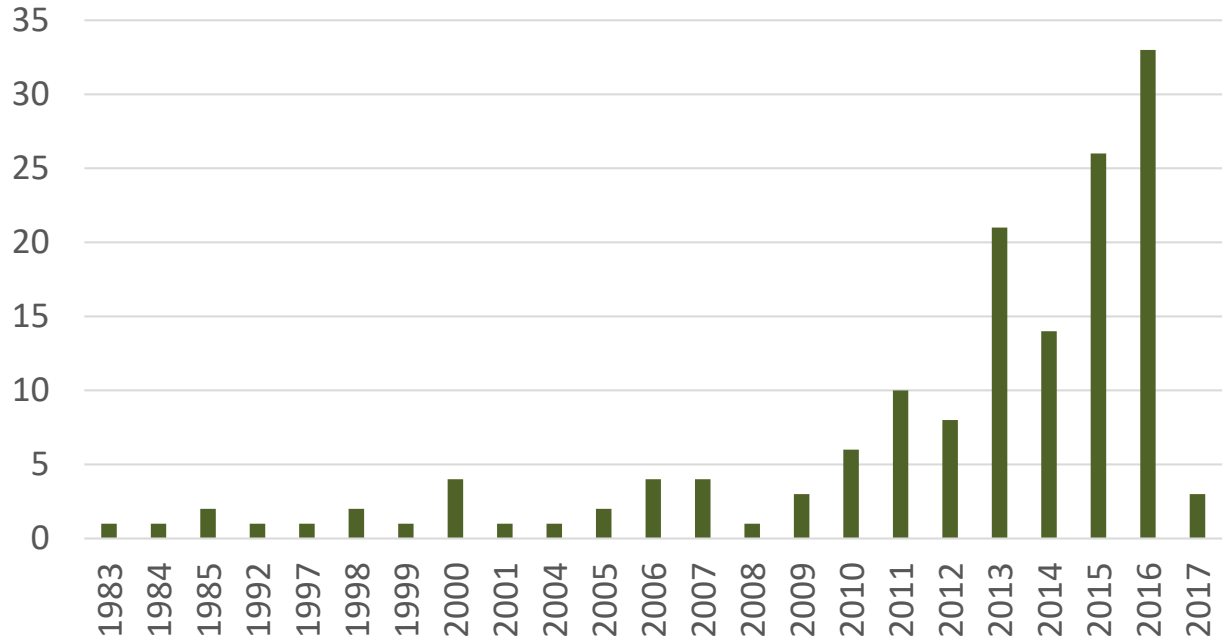
Mechanisms for Nature & Health

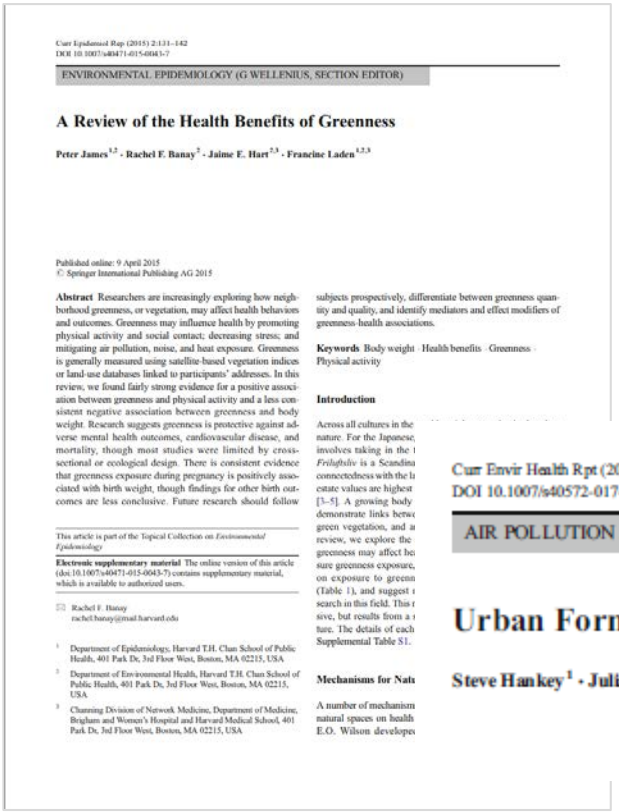


Hartig et al. 2014

Epidemiologic Studies of the Health Effects of Greenness

Manuscripts on “Greenness” in Humans in PubMed





Curr Epidemiol Rep (2015) 2:131–142
DOI 10.1007/s40471-015-0043-7

ENVIRONMENTAL EPIDEMIOLOGY (G WELLENIUS, SECTION EDITOR)

A Review of the Health Benefits of Greenness

Peter James[1,2] · Rachel F. Banay[2] · Jaime E. Hart[2,3] · Francine Laden[1,2,3]

Published online: 9 April 2015

Abstract Researchers are increasingly exploring how neighborhood greenness, or vegetation, may affect health behaviors and outcomes. Greenness may influence health by promoting physical activity and social contact; decreasing stress; and mitigating air pollution, noise, and heat exposure. Greenness is generally measured using satellite-based vegetation indices or land-use databases linked to participants' addresses. In this review, we found fairly strong evidence for a positive association between greenness and physical activity and a less consistent negative association between greenness and body weight. Research suggests greenness is protective against adverse mental health outcomes, cardiovascular disease, and mortality, though most studies were limited by cross-sectional or ecological design. There is consistent evidence that greenness exposure during pregnancy is positively associated with birth weight, though findings for other birth outcomes are less conclusive. Future research should follow subjects prospectively, differentiate between greenness quantity and quality, and identify mediators and effect modifiers of greenness-health associations.

Keywords Body weight · Health benefits · Greenness · Physical activity

Introduction

Across all cultures in the
nature. For the Japanese,
involves taking in the
Friluftsliv is a Scandina
connectedness with the l
estate values are highest
[3–5]. A growing body
demonstrate links betwe
green vegetation, and a
review, we explore the
greenness may affect he
sure greenness exposure,
on exposure to greenn
(Table 1), and suggest
search in this field. This
sive, but results from a
ture. The details of each
Supplemental Table S1.

Mechanisms for Natu

A number of mechanism
natural spaces on health
E.O. Wilson developed

This article is part of the Topical Collection on *Environmental Epidemiology*

Electronic supplementary material The online version of this article (doi:10.1007/s40471-015-0043-7) contains supplementary material, which is available to authorized users.

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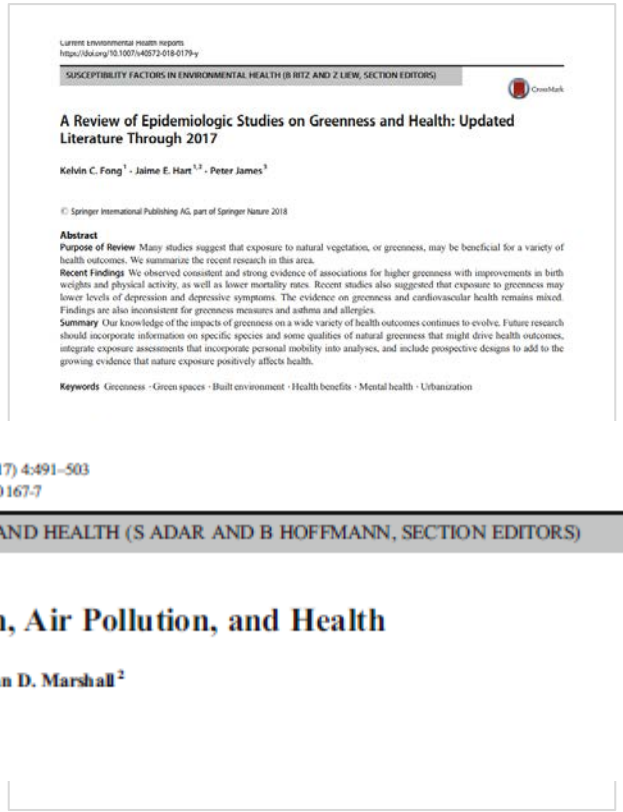


Current Environmental Health Reports
https://doi.org/10.1007/s40572-018-0179-y

SUSCEPTIBILITY FACTORS IN ENVIRONMENTAL HEALTH (B RITZ AND Z LIEW, SECTION EDITORS)

A Review of Epidemiologic Studies on Greenness and Health: Updated Literature Through 2017

Kelvin C. Fong[1] · Jaime E. Hart[1,2] · Peter James[3]

Abstract
Purpose of Review Many studies suggest that exposure to natural vegetation, or greenness, may be beneficial for a variety of health outcomes. We summarize the recent research in this area.
Recent Findings We observed consistent and strong evidence of associations for higher greenness with improvements in birth weights and physical activity, as well as lower mortality rates. Recent studies also suggested that exposure to greenness may lower levels of depression and depressive symptoms. The evidence on greenness and cardiovascular health remains mixed. Findings are also inconsistent for greenness measures and asthma and allergies.
Summary Our knowledge of the impacts of greenness on a wide variety of health outcomes continues to evolve. Future research should incorporate information on specific species and some qualities of natural greenness that might drive health outcomes, integrate exposure assessments that incorporate personal mobility into analyses, and include prospective designs to add to the growing evidence that nature exposure positively affects health.

Keywords Greenness · Green spaces · Built environment · Health benefits · Mental health · Urbanization

International Journal of Women's Health
Dovepress
REVIEW

Residential greenness: current perspectives on its impact on maternal health and pregnancy outcomes

This article was published in the following Dove Press journal:
International Journal of Women's Health
28 February 2017
Number of times this article has been viewed

Rachel F Banay[1,2]
Carla P Bezold[2,3]
Peter James[1–3]
Jaime E Hart[1,2]
Francine Laden[1–3]

[1]Department of Environmental Health, [2]Department of Epidemiology, Harvard T.H. Chan School of Public Health, [3]Channing Division of Network Medicine, Department of Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA

Abstract: Recent research in environmental epidemiology has attempted to estimate the effects of exposure to nature, often operationalized as vegetation, on health. Although many analyses have focused on vegetation or greenness with regard to physical activity and weight status, an incipient area of interest concerns maternal health and birth outcomes. This paper reviews 14 studies that examined the association between greenness and maternal or infant health. Most studies were cross-sectional and conducted in birth cohorts. Several studies found evidence for positive associations between greenness and birth weight and maternal peripartum depression. Few studies found evidence for an association between greenness and gestational age or other birth outcomes, or between greenness and preeclampsia or gestational diabetes. Several assessed effect modification by individual or area-level socioeconomic status and found that effects were stronger among those of lower socioeconomic status. Few studies conducted mediation analyses of any kind. Future research should include more diverse birth outcomes and focus on maternal health (especially mental health) and capitalize on richer exposure information during pregnancy rather than cross-sectional assessment at birth.
Keywords: greenness, green space, birth outcomes, prenatal health, infant health

Introduction

In recent years, environmental epidemiologists have turned their attention to the potential health effects of exposure to nature. Exposure to nature is thought to affect health in several ways. Natural environments may promote health by providing opportunities for routine and recreational physical activity.[1] They may have a therapeutic effect on mental health.[2] They may facilitate social interactions and social cohesion, demonstrated to provide benefits to health.[3] Vegetation may also lower harmful exposures, for example, by filtering air pollution,[4] buffering noise,[5] or alleviating thermal discomfort.[6] In concert, these effects could help produce healthier pregnancies and better birth outcomes.

In scientific analyses, exposure to nature is often conceptualized as exposure to vegetation, hence the development of a literature concerned with greenness or green space. So far, studies have provided some evidence for a positive association between greenness exposure and physical activity, weight, heart disease, mental health, and developmental outcomes, among others.[2] Some of these topics have received greater attention than others, and the evidence on a relationship between greenness and maternal health and birth outcomes is still developing. Researchers continue to attempt to isolate the effects of nature from socioeconomic status and to disentangle it from

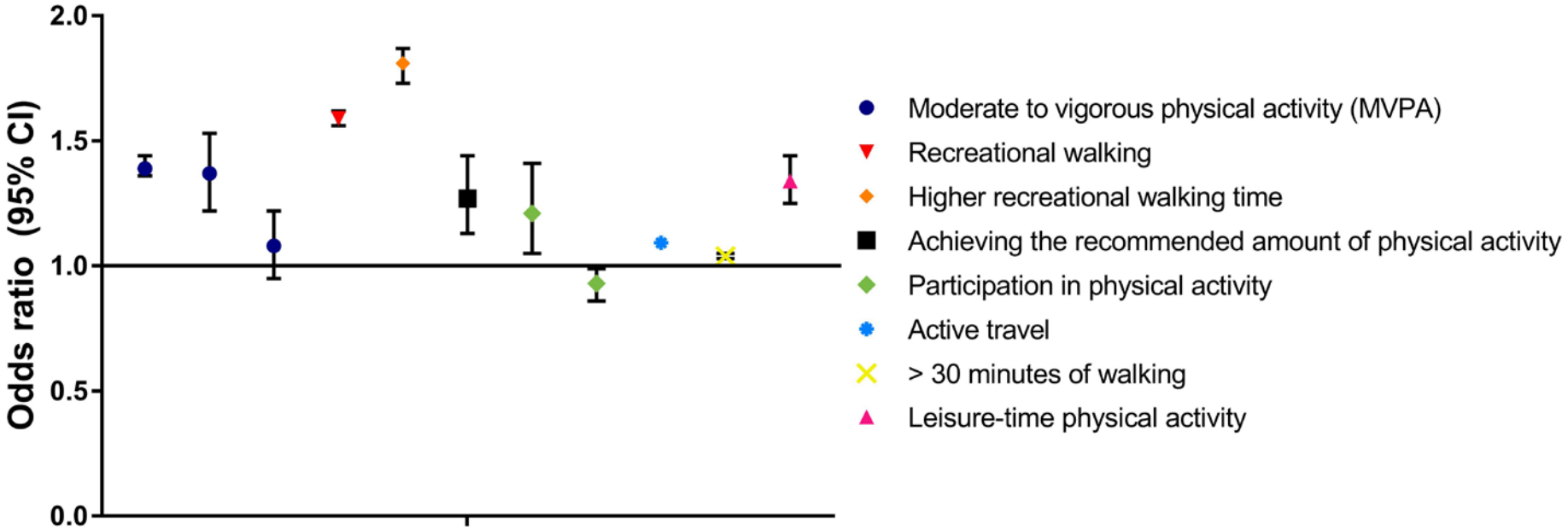
Curr Envir Health Rpt (2017) 4:491–503
DOI 10.1007/s40572-017-0167-7

AIR POLLUTION AND HEALTH (S ADAR AND B HOFFMANN, SECTION EDITORS)

Urban Form, Air Pollution, and Health

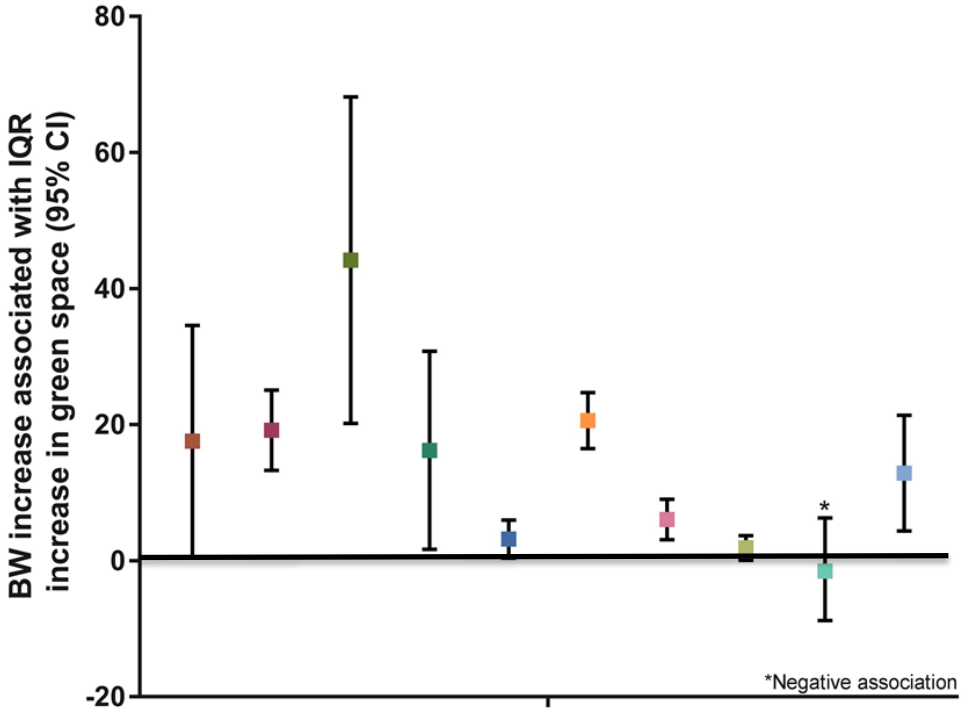
Steve Hankey[1] · Julian D. Marshall[2]

Greenness and Physical Activity



Authors as reported from left to right on graph: *Almanza et al. (2012); Wheeler et al. (2010); Wheeler et al. (2010); Chaix et al. (2014); Chaix et al. (2014); Mytton et al. (2012); Gong et al. (2014); Prince et al. (2011); Sarkar (2017); Sakar (2017); McMorris et al. (2015).*

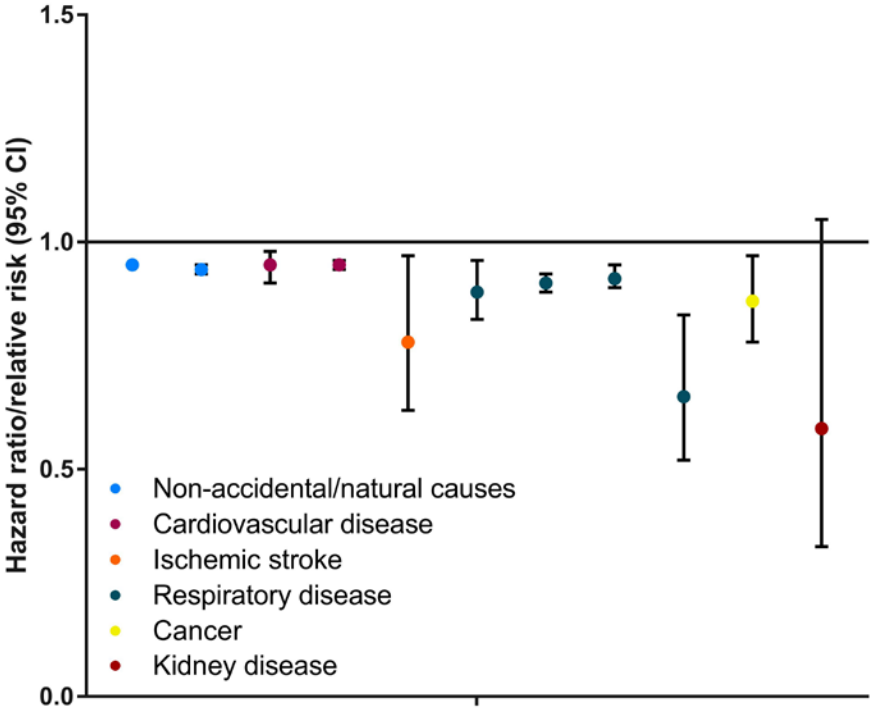
Greenness and Birth Weight



Authors as reported from left to right on graph: *Markevych et al. (2014); Agay-Shay et al. (2014); Dadvand et al. (2012); Dadvand et al. (2014); Ebisu et al. (2016); Hystad et al. (2014).; Laurent et al. (2013); Cusack et al. (2017); Cusack et al. (2017).*

- ~20 studies
- Most find increases in birthweight with increases in surrounding greenness
- Definitions of the exposure vary widely across studies and study locations

Greenness and Mortality



- ~20 studies
- Across many countries, increases in greenness, green space, or park access associated with reduced mortality
- As with other outcomes, wide variation in specific exposures examined
- Some early evidence of stronger effects for cardiovascular disease (CVD) and cancer

Authors as reported from left to right on graph: *McMorris et al. (2015); Vienneau et al. (2017); Richardson & Mitchell (2010); Richardson & Mitchell (2010); Wilker et al. (2014); Richardson & Mitchell (2010); Villeneuve et al. (2012); Villeneuve et al. (2017); James et al. (2016); James et al. (2016); James et al. (2016).*

ehp ENVIRONMENTAL HEALTH PERSPECTIVES

Research

A Section 508–conformant HTML version of this article is available at http://dx.doi.org/10.1289/ehp.1510363.

Exposure to Greenness and Mortality in a Nationwide Prospective Cohort Study of Women

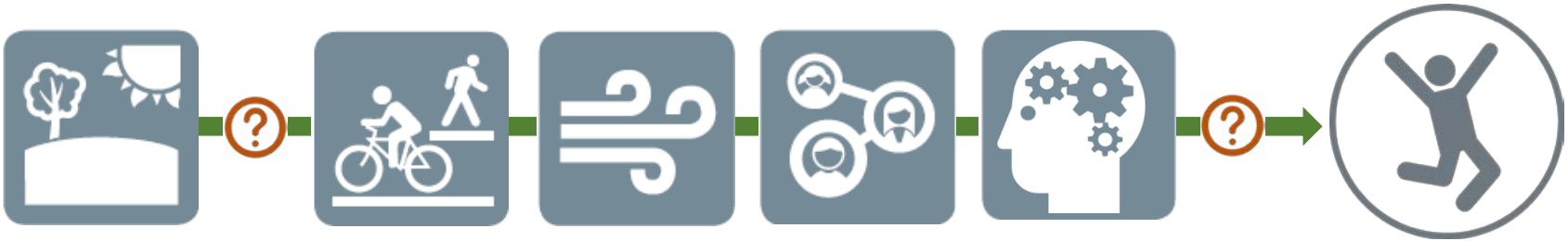
Peter James,[1,2] Jaime E. Hart,[2,3] Rachel F. Banay,[2] and Francine Laden[1,2,3]

[1]Department of Epidemiology, and [2]Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA; [3]Channing Division of Network Medicine, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts, USA

Greenness and mortality

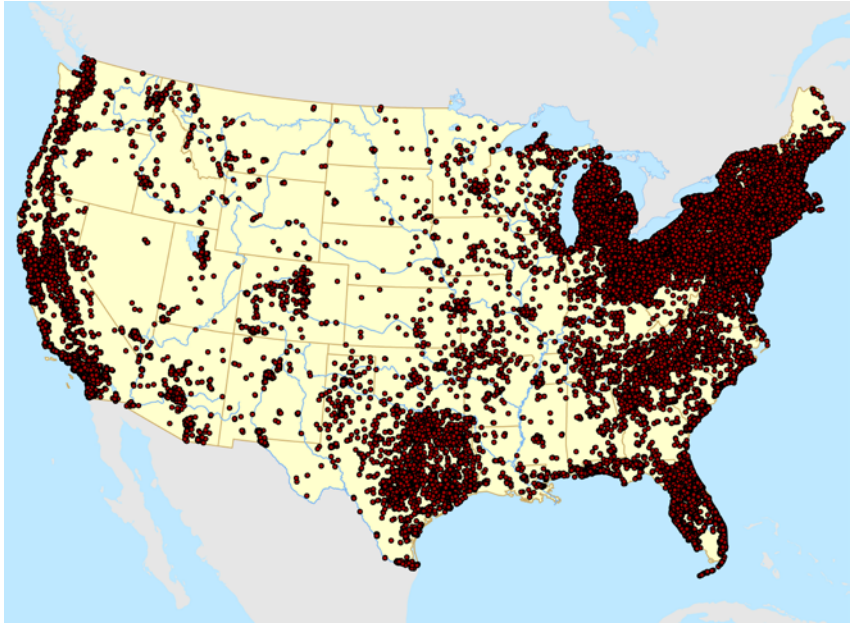
Motivation: Few studies had examined the effect of greenness on mortality risk

Study Goal: Examine the association between surrounding residential greenness and all-cause mortality in the Nurses' Health Study (NHS) from 2000-2008



Population: Nurses' Health Study

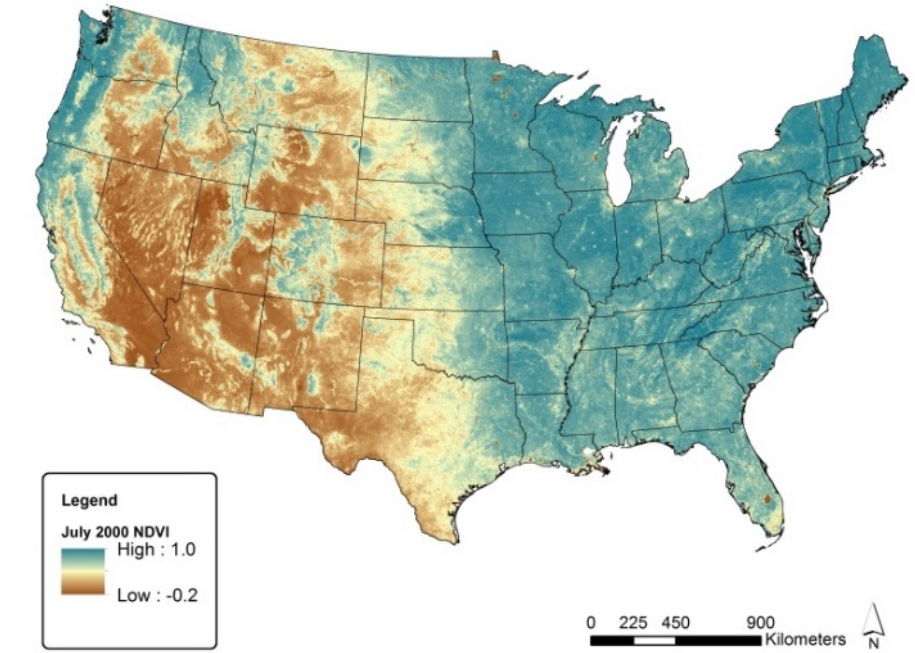
- Began in 1976 with 121,701 female nurses aged 30-55
- Originally from 11 States, have moved throughout the United States
- Biennial questionnaires with disease and mortality follow-up
- Residential mailing addresses geocoded from 1986-2014



Location of NHS residential addresses 2000-2008

Exposure: Greenness

- Normalized Difference Vegetation Index (NDVI)
  - **MODIS** satellite data on vegetation quantity at 250m resolution from 2000-2008
  - Mean NDVI value surrounding nurses' residential addresses
  - Time-varying measures for each season



NDVI Data for July 2000

How is NDVI Calculated?

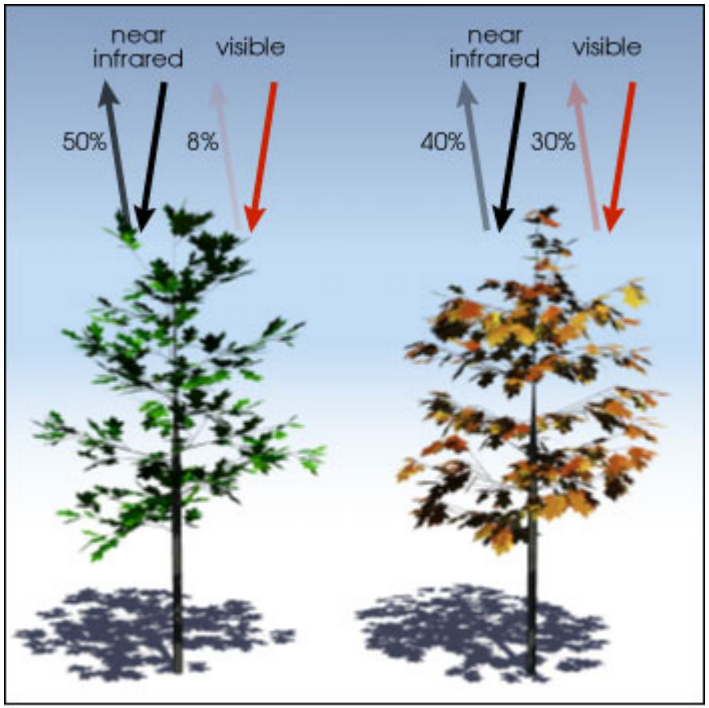


Image: NASA

Image: Sentera Inc

Greenness and All-Cause Mortality in the Nurse's Health Study (N=108,630 from 2000-2008)

	Cumulative Average Greenness Fully Adjusted HR (95% CI)
Greenness Quintile 1	Ref
Greenness Quintile 2	0.92 (0.86, 0.98)
Greenness Quintile 3	0.90 (0.84, 0.96)
Greenness Quintile 4	0.94 (0.88, 1.00)
Greenness Quintile 5	0.88 (0.82, 0.94)
P for Trend	0.002

Hazard ratios are adjusted for calendar time, age, race, smoking, individual SES, Census tract median home value and income

James et al. Environ Health Perspect 2016 124:1344–1352

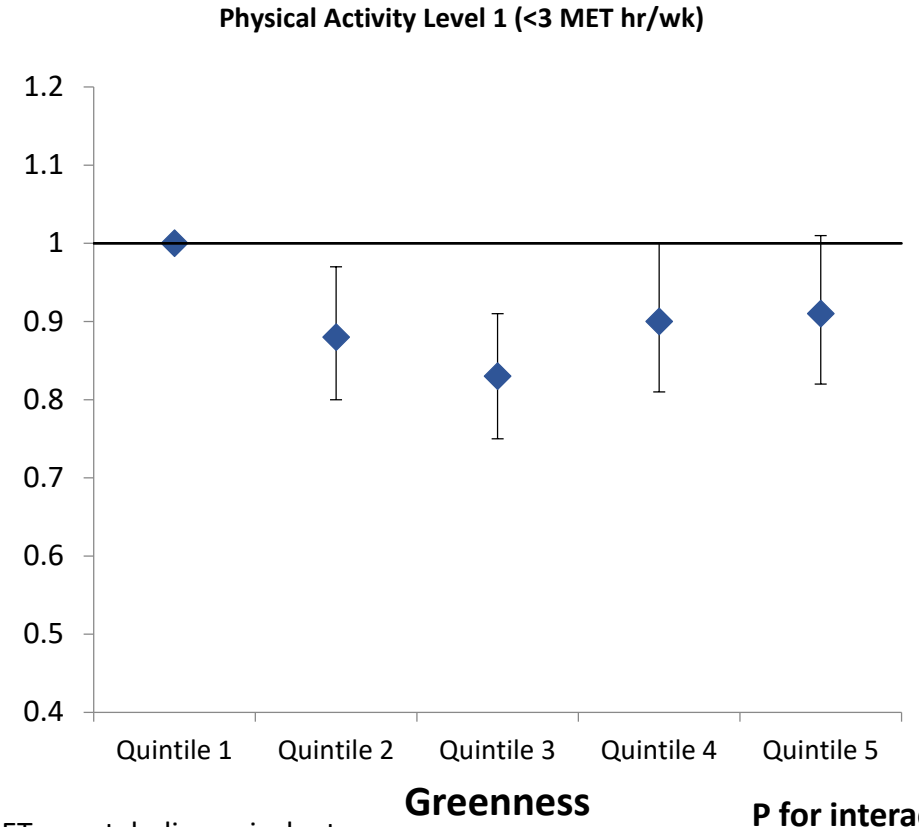
Cause-Specific Mortality Findings

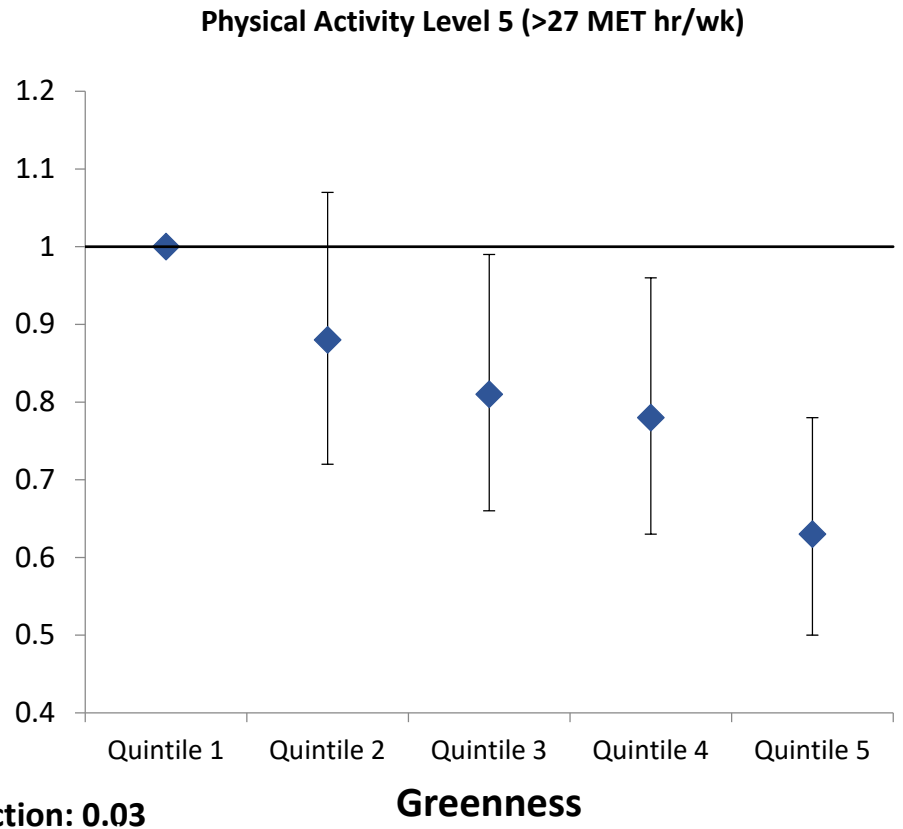
	Cumulative Average Greenness	
	Cancer Mortality (3,363 Cases)	Respiratory Mortality (766 Cases)
Quintile 1	Ref	Ref
Quintile 2	0.93 (0.84, 1.03)	0.84 (0.69, 1.04)
Quintile 3	0.90 (0.81, 1.00)	0.86 (0.69, 1.06)
Quintile 4	0.93 (0.83, 1.03)	0.75 (0.60, 0.94)
Quintile 5	0.87 (0.78, 0.97)	0.66 (0.52, 0.84)
P for Trend	0.024	<0.001

Hazard ratios are adjusted for calendar time, age, race, smoking, individual SES, Census tract median home value and income

James et al. Environ Health Perspect 2016 124:1344–1352

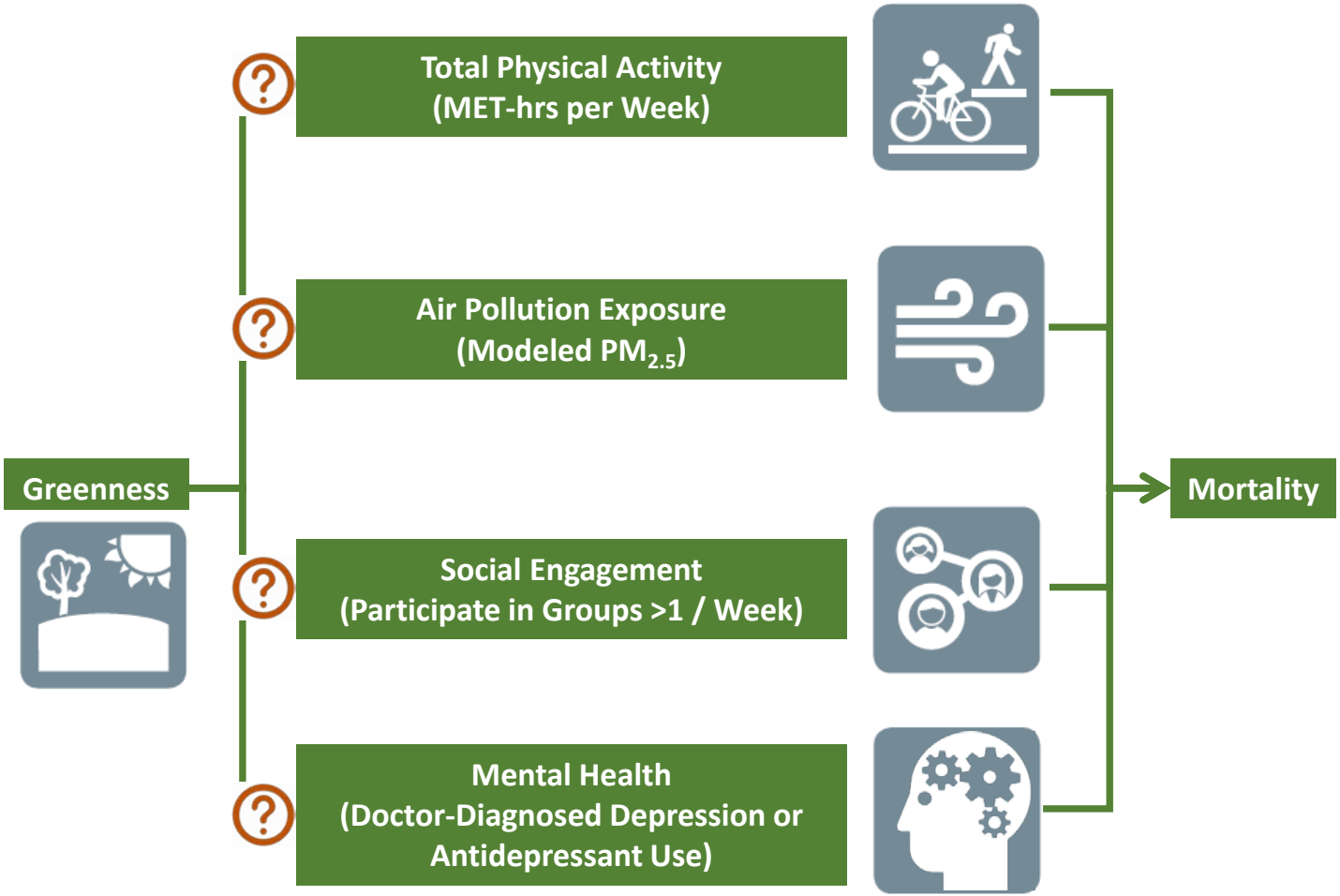
Results: All-Cause Mortality Analyses Stratified by Self-Reported Physical Activity

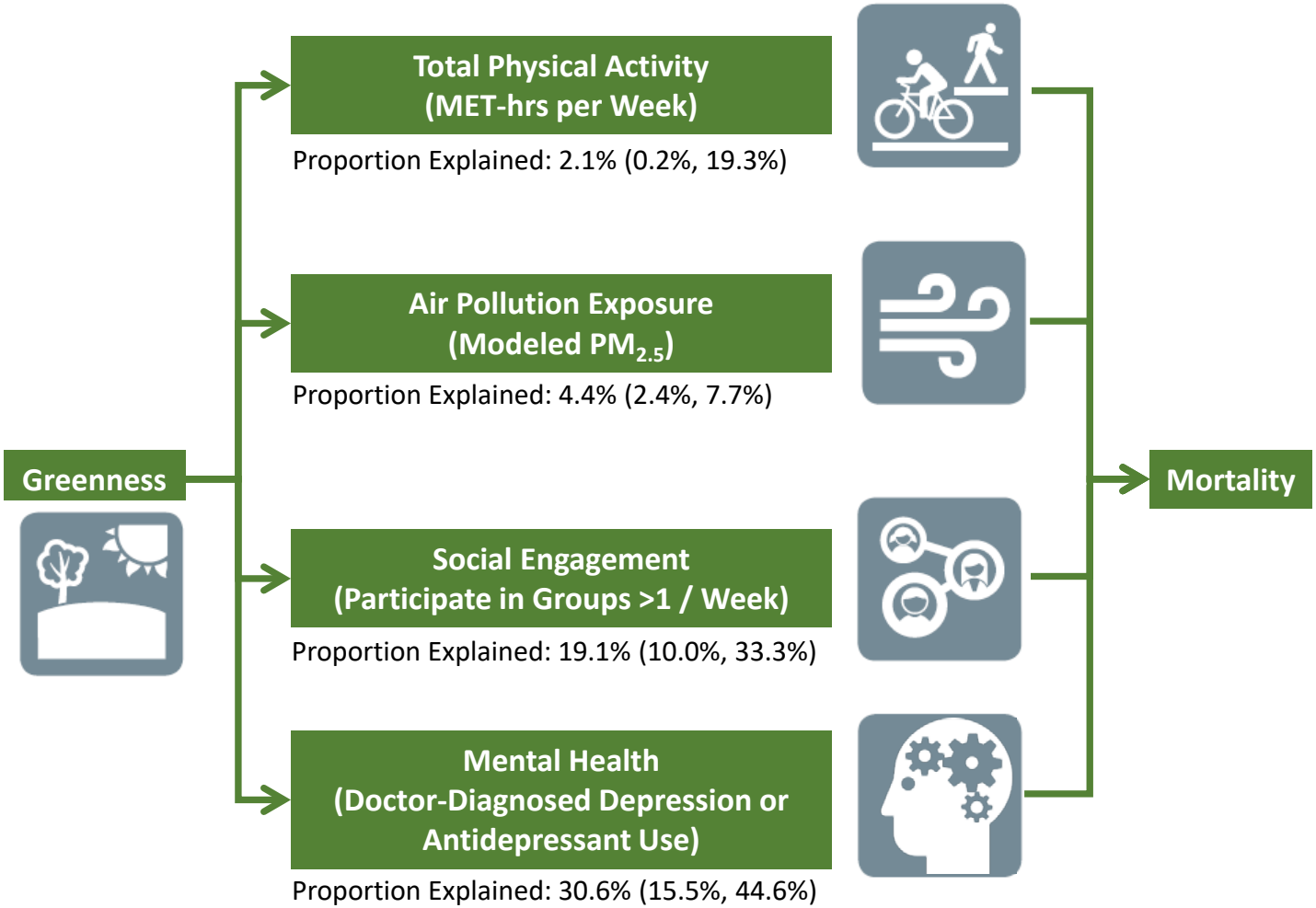




P for interaction: 0.03

MET = metabolic equivalent


Total Physical Activity
(MET-hrs per Week)
Air Pollution Exposure
(Modeled $PM_{2.5}$)
Greenness
Social Engagement
(Participate in Groups >1 / Week)
Mental Health
(Doctor-Diagnosed Depression or
Antidepressant Use)
Mortality


Greenness
Total Physical Activity (MET-hrs per Week)
Proportion Explained: 2.1% (0.2%, 19.3%)
Air Pollution Exposure (Modeled $PM_{2.5}$)
Proportion Explained: 4.4% (2.4%, 7.7%)
Social Engagement (Participate in Groups >1 / Week)
Proportion Explained: 19.1% (10.0%, 33.3%)
Mental Health (Doctor-Diagnosed Depression or Antidepressant Use)
Proportion Explained: 30.6% (15.5%, 44.6%)
Mortality

Strengths

- ❑Large nationwide prospective cohort study with time-varying exposure data
- ❑Adds evidence to mechanisms with mediation analyses

Limitations

- Female nurses, primarily white
  - Limited generalizability
- Is greenness around the home the right measure?
  - No description of quality of nature
  - No information on how participants interact with nature

Higher levels of greenness associated with a decreased rates of all-cause mortality in this cohort of female nurses, after accounting for numerous potential confounders.

Evidence of mediation by **mental health, social engagement, air pollution, and physical activity.**

Outline

Health effects of greenness

Interrelationships between greenness and air pollution

Impacts of greenness and air pollution on health

Multiple Correlated Contextual Factors

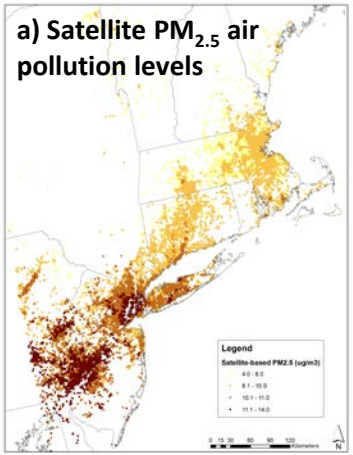
ORIGINAL ARTICLE

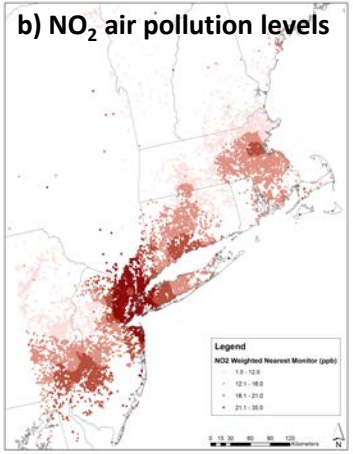
Interrelationships Between Walkability, Air Pollution, Greenness, and Body Mass Index

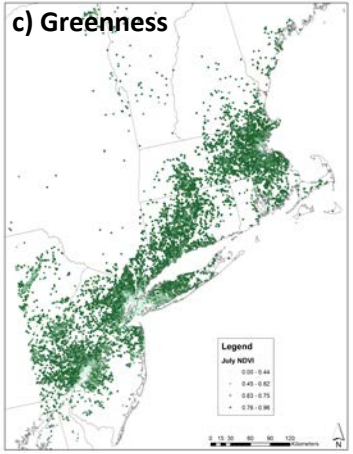
Peter James,[a,b,c] *Marianthi-Anna Kioumourtzoglou,*[d] *Jaime E. Hart,*[b,c] *Rachel F. Banay,*[b] *Itai Kloog,*[e] *and Francine Laden*[a,b,c]

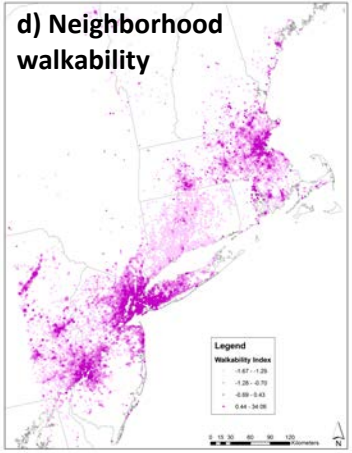
Background: Recent studies have linked urban environmental factors and body mass index (BMI); however, such factors are often examined in isolation, ignoring correlations across exposures.
Methods: Using data on Nurses' Health Study participants living in the Northeastern United States in 2006, we estimated associations between neighborhood walkability (a composite of population between walkability and BMI existed only among younger participants (<71 years old).
Conclusions: Neighborhood walkability was nonlinearly linked to lower BMI independent of air pollution and greenness. Our findings highlight the importance of accounting for nonlinear confounding by interrelated urban environmental factors when investigating associations between the environment and BMI.

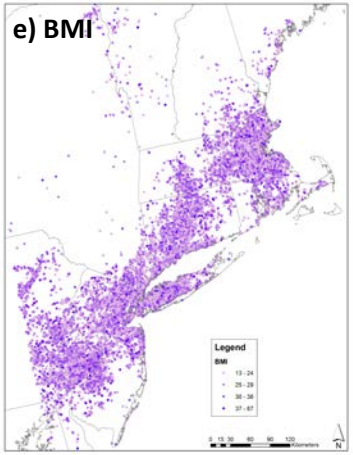
CORRELATED CONTEXTUAL FACTORS

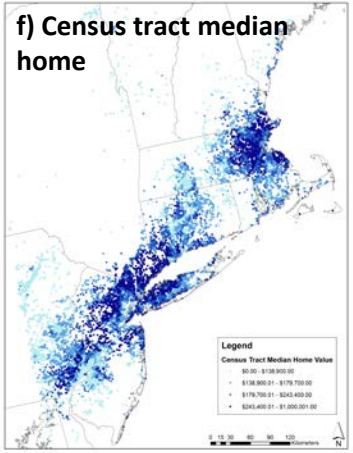












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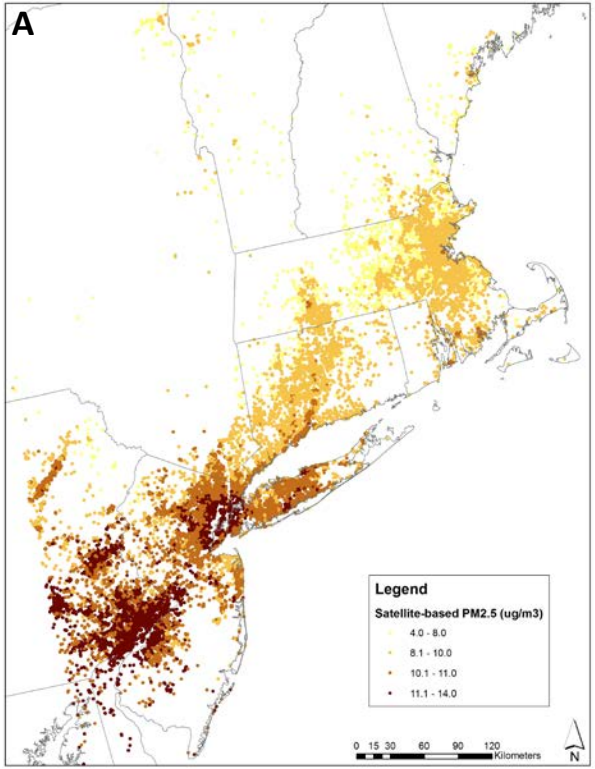

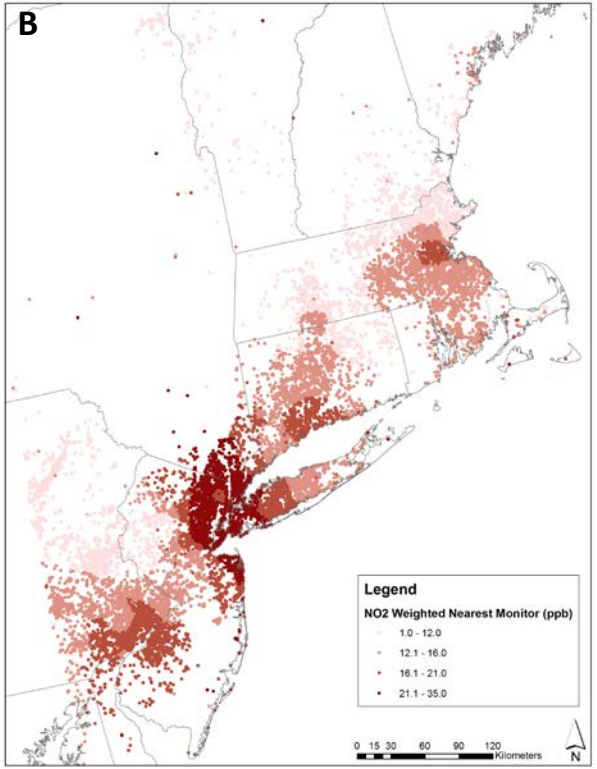

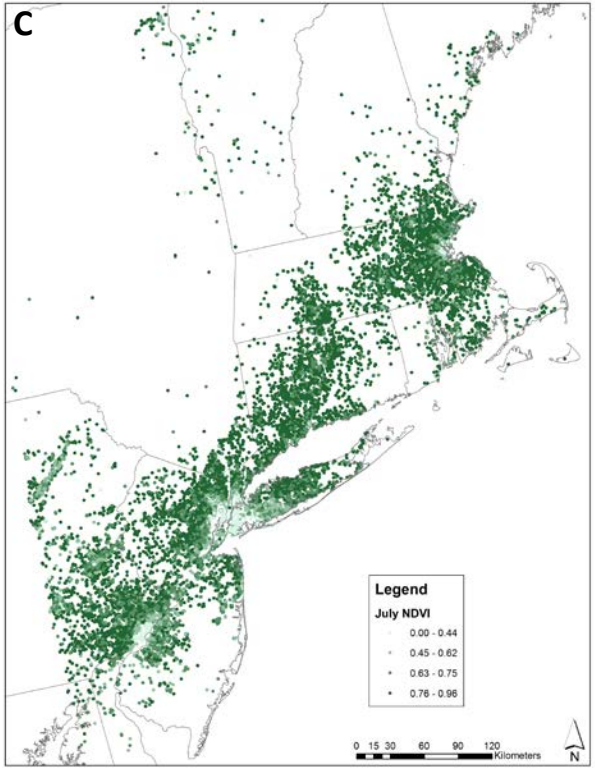

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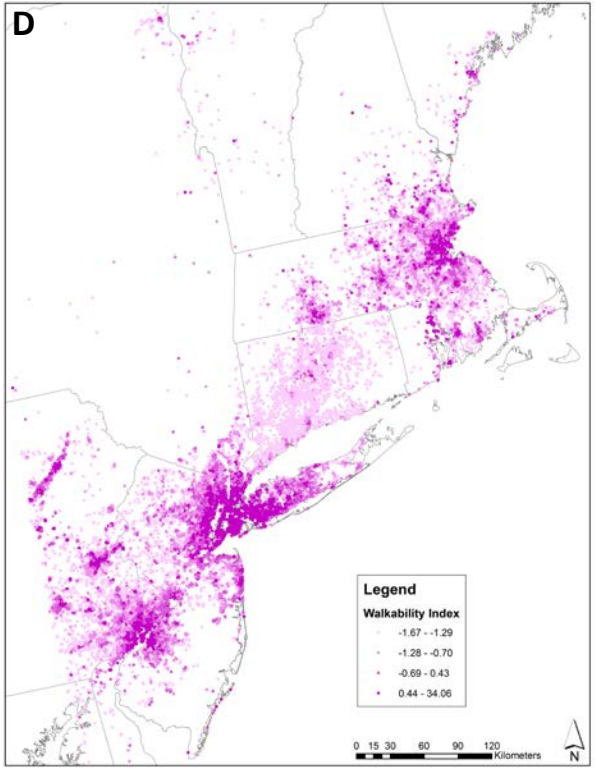

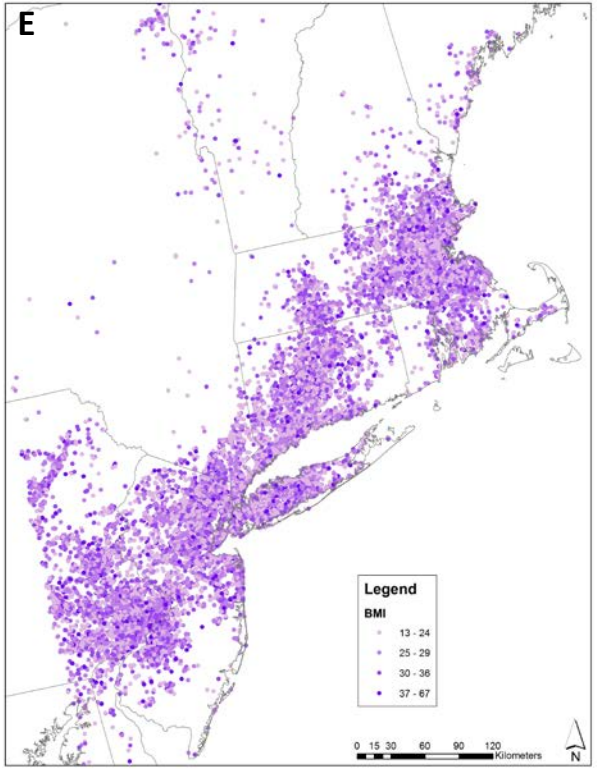

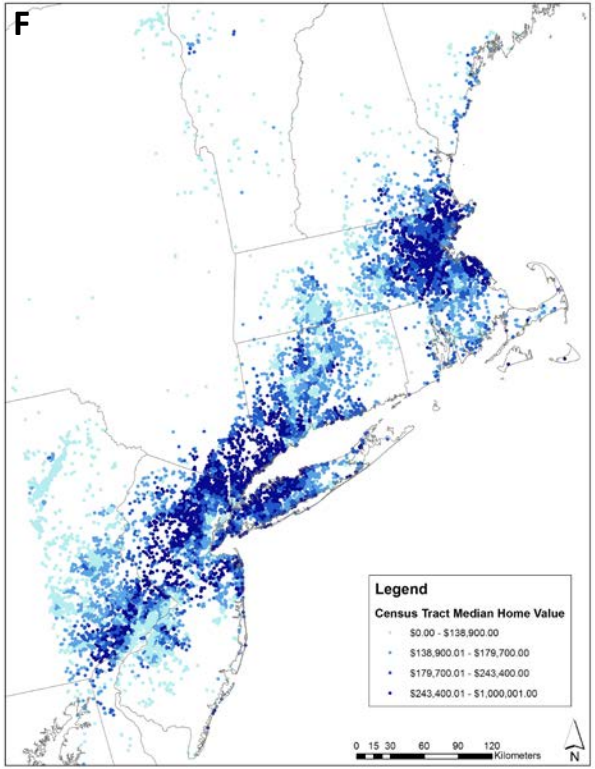

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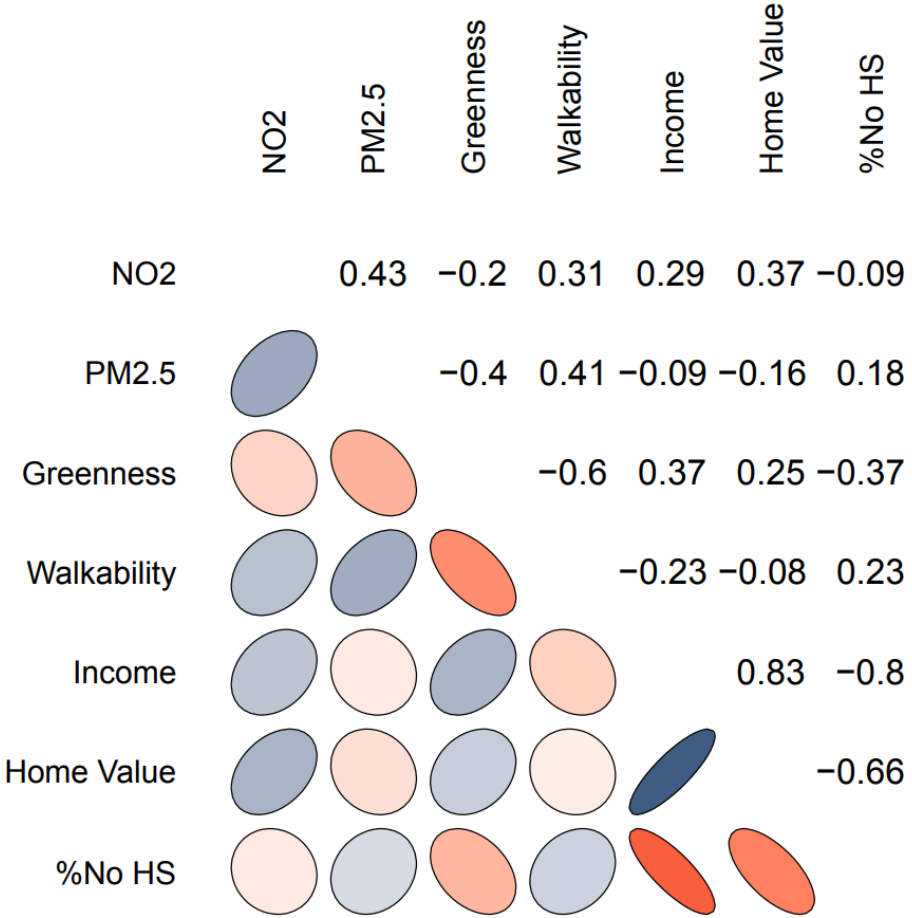


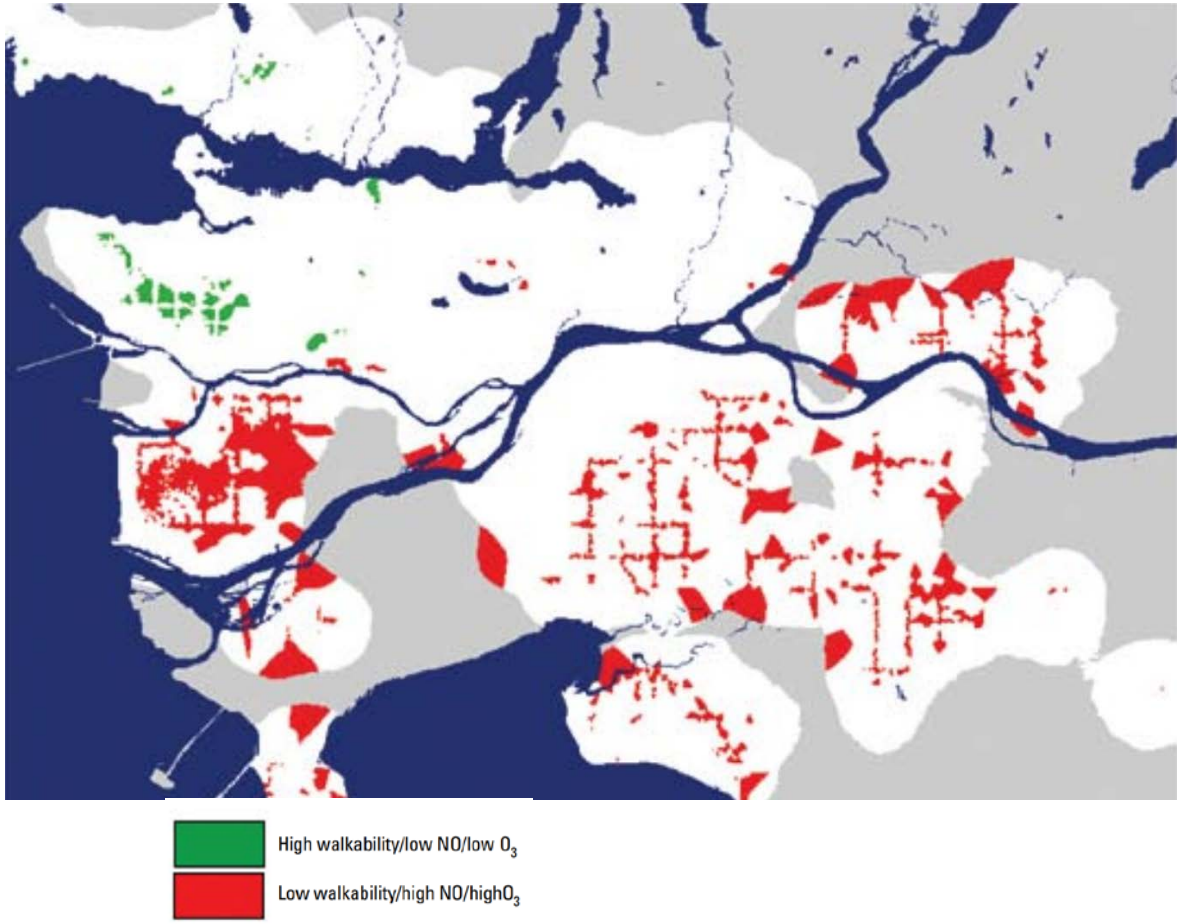
HS = high school

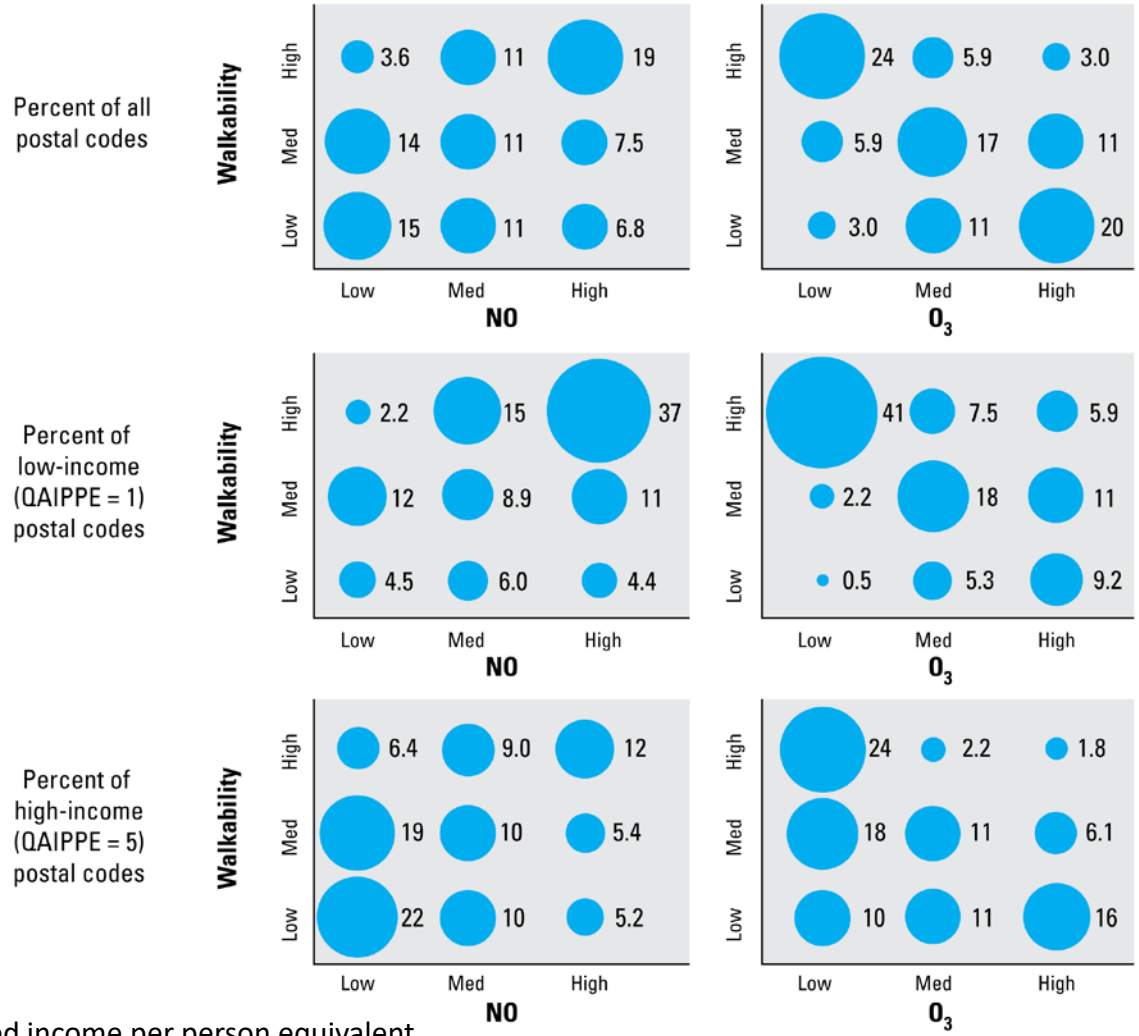
Research

Healthy Neighborhoods: Walkability and Air Pollution

Julian D. Marshall,[1] Michael Brauer,[2] and Lawrence D. Frank[3]

[1]Department of Civil Engineering, University of Minnesota, Minneapolis, Minnesota, USA; [2]School of Environmental Health, and [3]School of Community and Regional Planning, University of British Columbia, Vancouver, British Columbia, Canada


High walkability/low NO/low O_3
Low walkability/high NO/highO_3



QAIPPE = quintile of adjusted income per person equivalent

Outline

Health effects of greenness

Interrelationships between greenness and air pollution

Impacts of greenness and air pollution on health

Current Literature

- ~40 studies have examined the associations of both air pollution and a measure of greenness with health outcomes
- The majority have looked at mediation or confounding, not effect modification
- Of studies that have examined effect modification, most have not observed it

ORIGINAL ARTICLE

Interrelationships Between Walkability, Air Pollution, Greenness, and Body Mass Index

Peter James,[a,b,c] *Marianthi-Anna Kioumourtzoglou,*[d] *Jaime E. Hart,*[b,c] *Rachel F. Banay,*[b] *Itai Kloog,*[e] *and Francine Laden*[a,b,c]

Background: Recent studies have linked urban environmental factors and body mass index (BMI); however, such factors are often examined in isolation, ignoring correlations across exposures.

Methods: Using data on Nurses' Health Study participants living in the Northeastern United States in 2006, we estimated associations between neighborhood walkability (a composite of population between walkability and BMI existed only among younger participants (<71 years old).

Conclusions: Neighborhood walkability was nonlinearly linked to lower BMI independent of air pollution and greenness. Our findings highlight the importance of accounting for nonlinear confounding by interrelated urban environmental factors when investigating associations between the environment and BMI.

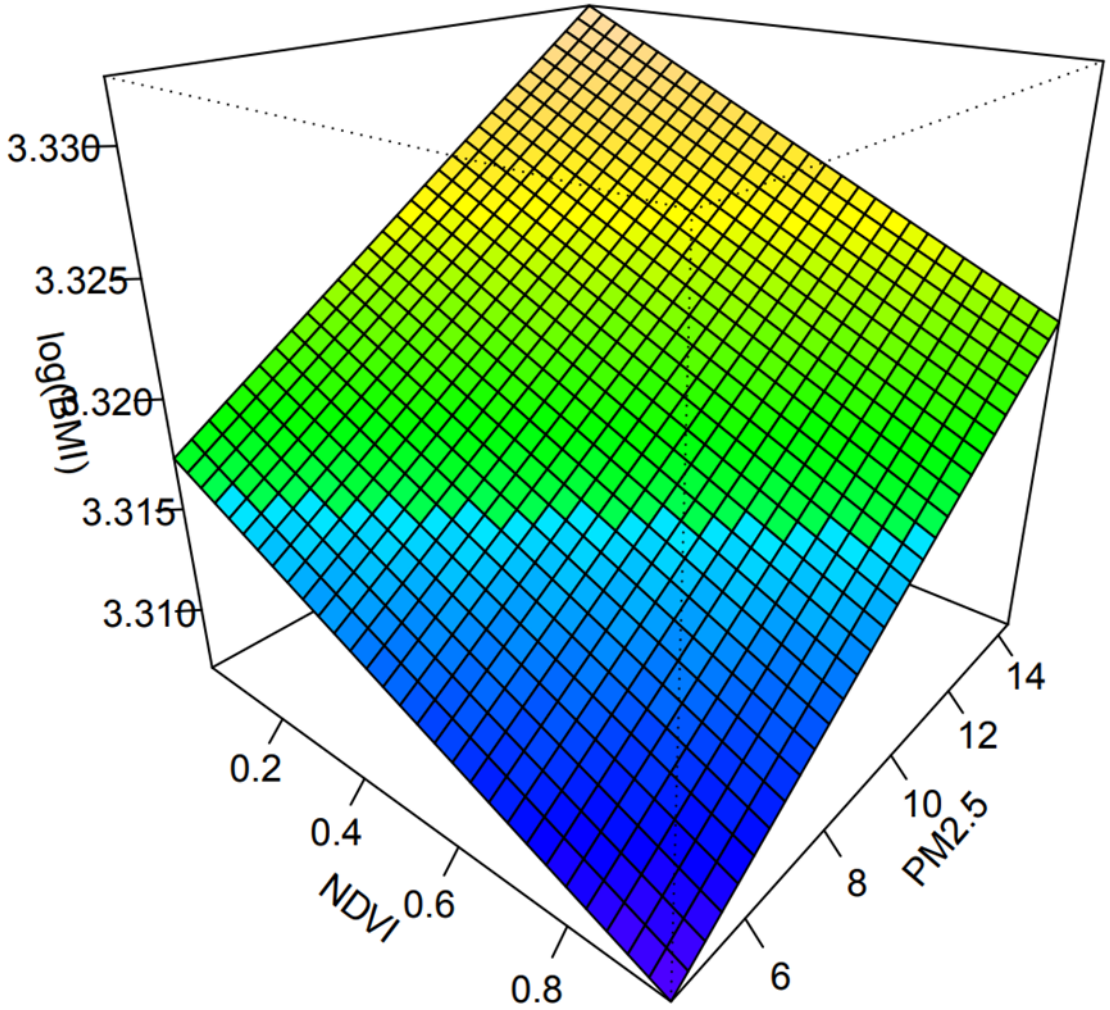
Study Design

- 23,435 NHS Participants, aged 60-87
  - Lived in the Northeast with a street level geocode
  - BMI calculated from reported height & weight
- Address level data on exposures to:
  - Walkability (index of population density, business counts, intersection counts), $PM_{2.5}$, NO_2, NDVI in 250 and 1250m buffers
- Adjusted for age, race, smoking status, individual and neighborhood level SES
- Generalized added mixed models to explore single and multiple exposure dose-responses and explore non-linearity

NHS = Nurses' Health Study

Results

- In single exposure models, the dose-responses were non-linear for $PM_{2.5}$, walkability, and greenness
- In four exposure models, only walkability was nonlinear
- There was no effect modification of pollution effects by greenness


3.330
3.325
3.320
3.315
3.310
log(BMI)
0.2
0.4
0.6
0.8
NDVI
6
8
10
12
14
PM2.5

International Journal of
Environmental Research and Public Health

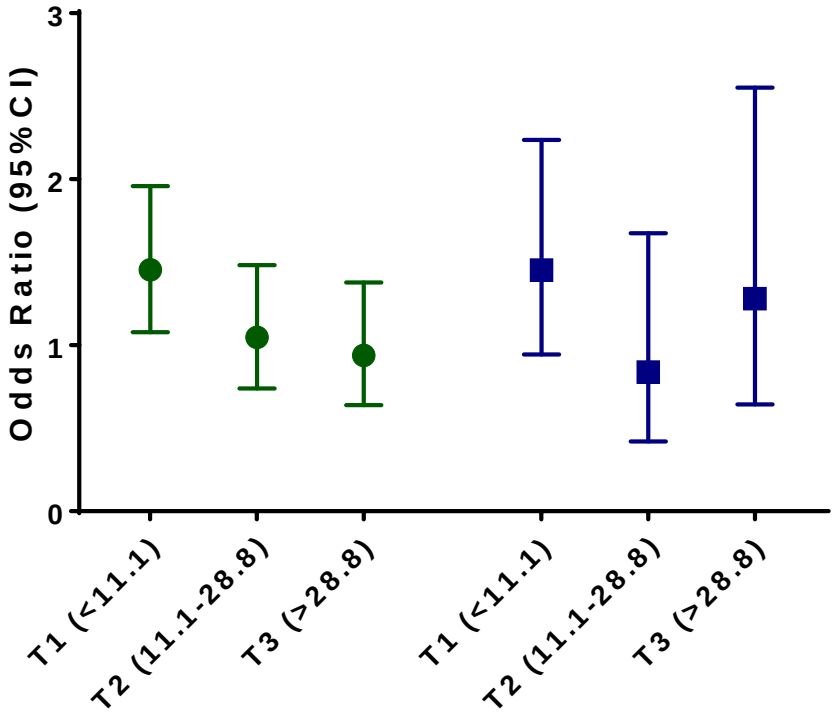
MDPI

Article

Preventive Effect of Residential Green Space on Infantile Atopic Dermatitis Associated with Prenatal Air Pollution Exposure

Ji-Young Lee [1], Dirga Kumar Lamichhane [2], Myeongjee Lee [1], Shinhee Ye [1], Jung-Hyun Kwon [3], Myung-Sook Park [4], Hwan-Cheol Kim [2], Jong-Han Leem [2], Yun-Chul Hong [5], Yangho Kim [6], Mina Ha [7] and Eunhee Ha [1,*]

Risk of Atopic Dermatitis at age 6



- Cohort of 659 mother-child pairs in Korea
- PM_{10} and NO_2 from land use regression (LUR) models during pregnancy
- Green space from land use maps

Environment International 99 (2017) 170–176

Contents lists available at ScienceDirect

Environment International

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

The association of air pollution and greenness with mortality and life expectancy in Spain: A small-area study

Carmen de Keijzer [a,b,c], David Agis [a,b,c], Albert Ambrós [a,b,c], Gustavo Arévalo [d], Jose M Baldasano [d,e], Stefano Bande [f], Jose Barrera-Gómez [a,b,c], Joan Benach [g,h,i], Marta Cirach [a,b,c], Payam Dadvand [a,b,c], Stefania Ghigo [f], Èrica Martinez-Solanas [a,b,c], Mark Nieuwenhuijsen [a,b,c], Ennio Cadum [j], Xavier Basagaña [a,b,c,*], on behalf of the MED-HISS Study group [1]:

Correlations Between Exposures

Table S2. Spearman correlation coefficients between the different exposures and confounders

	PM_{10}	$PM_{2.5}$	NO_2	O_3	NDVI	Ind. vul.[a]	LC SMR[b]
$PM_{2.5}$	0.91						
NO_2	0.37	0.55					
O_3	0.50	0.33	-0.21				
NDVI	-0.48	-0.40	0.05*	-0.45			
Index of vulnerability	0.26	0.12	-0.44	0.30	-0.31		
Lung cancer SMR	0.16	0.18	0.18	-0.06	-0.07	0.09	
Population	0.46	0.49	0.61	0.07	-0.20	-0.24	0.18

SMR = standardized mortality ratio

Table S5. Effects of air pollutants at the 5th and 95th percentiles of NDVI. Results derived from the models with interaction terms presented in Table S4.

	Rural		Urban	
	Effect at 5th percentile of NDVI	Effect at 95th percentile of NDVI	Effect at 5th percentile of NDVI	Effect at 95th percentile of NDVI
RR				
PM_{10} (5 $\mu g/m^3$)	1.156	1.129	1.029	1.065*
$PM_{2.5}$ (2 $\mu g/m^3$)	1.119	1.098	1.008	1.051*
NO_2 (5 $\mu g/m^3$)	1.025	1.067*	0.991	1.017*
O_3 (5 $\mu g/m^3$)	1.082	1.007*	1.018	1.023
Change in LE				
PM_{10} (5 $\mu g/m^3$)	-1.81	-1.42*	-0.37	-0.65
$PM_{2.5}$ (2 $\mu g/m^3$)	-1.47	-1.01*	-0.13	-0.63*
NO_2 (5 $\mu g/m^3$)	-0.44	-0.67	0.08	-0.18*
O_3 (5 $\mu g/m^3$)	-1.02	-0.12*	-0.12	-0.18

* The underlying model contains a statistically significant interaction term the between air pollutant and greenness (see Table S7).

RR = relative risk; LE = life expectancy

Key Results

- PM_{10}, $PM_{2.5}$, and O_3
  - In rural areas, stronger effects in areas with lower greenness.
  - In urban areas, stronger effects in areas with higher greenness.
- For NO_2 the effect was stronger in areas with higher greenness in both urban and rural areas.
- Protective associations of greenness with mortality and loss of life within areas with lower SES
- Higher greenness was associated with higher mortality and lower life expectancy in areas with a higher SES

Conclusions

- Strong hypothesized biological mechanisms for protective effects of nature
  - Early evidence supports these in panel studies and “real-world” exposure scenarios
- Growing evidence of impacts of exposure to natural environments and improved health for many outcomes
- Current exposure measures may not capture the key elements of nature that are beneficial, and may miss key attributes that are likely important
  - The majority of studies use residential or residential and work/school exposures, which may be more or less appropriate for certain outcomes
- Interrelationships with air pollution still need to be explored
  - Mediator, modifier, confounder?
  - Complex patterns in different parts of the world suggest specifics of urban form may also play a role along with SES
- Many studies addressing these issues are underway

Acknowledgements

- Francine Laden
- Peter James
- Trang VoPham
- Carla Bezold
- Rachel Banay
- Isabel Holland

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- R01 ES028033
- R01 ES017017
- P30 ES000002
- UM1 CA186107
- P01 CA87969
- UM1 CA176726
- K99/R00 CA201542


Thank You!
Questions?