Interrelationships Between Urban Green Space, Air Pollution, and Health

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Health effects of greenness

Interrelationships between greenness and air pollution

Impacts of greenness and air pollution on health
1. Health effects of greenness
2. Interrelationships between greenness and air pollution
3. Impacts of greenness and air pollution on health
Health effects of greenness

- Proposed mechanisms
- Observational studies
Mechanisms for Nature & Health

Natural environment
Examples:
- Type (e.g., urban park)
- Quality (e.g., species diversity)
- Amount (e.g., tree canopy near home)

Contact with nature as such
Examples:
- Frequency of contact
- Duration of contact
- Activity affordance (e.g., for viewing, for walking)

Air quality
Examples:
- Reduction of particulate matter
- Increase in ozone
- Increase in aeroallergens

Physical activity
Examples:
- Increased walking for recreation
- Increased outdoor play

Social contacts
Examples:
- Increased interaction with neighbors
- Increased sense of community

Health and well-being
Examples:
- Performance (e.g., academic, occupational)
- Subjective well-being (e.g., happiness)
- Persistent physiological changes (e.g., high cortisol levels)
- Mortality (e.g., CHD, depression)
- Longevity

Stress
Examples:
- Reduction of stressor exposures
- Acquisition of coping resources
- Affective, cognitive, physiological restoration

Effect modifiers 1
Examples: Distance, other accessibility factors, weather, perceived safety, societal/cultural context

Effect modifiers 2
Examples: Gender, age, socioeconomic status, occupation, societal/cultural context

Hartig et al. 2014
Epidemiologic Studies of the Health Effects of Greenness
Manuscripts on “Greenness” in Humans in PubMed
Urban Form, Air Pollution, and Health

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2Department of Atmospheric Sciences, University of Washington, Seattle, WA 98195, USA

Mechanism for NIT2

A mechanism for a relationship between air pollutants and health in the city of NIT2. We propose that exposure to urban air pollution, including nitrogen dioxide (NO2) and particulate matter (PM2.5), is associated with increased levels of inflammatory markers and oxidative stress, which in turn may contribute to the development of chronic diseases such as cardiovascular disease and respiratory conditions. The mechanism involves a complex interplay of factors, including ambient pollution levels, individual susceptibility, and local environmental characteristics.
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).
20 studies
Most find increases in birthweight with increases in surrounding greenness
Definitions of the exposure vary widely across studies and study locations

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).
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).
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 Laden¹,²,³

¹Department of Epidemiology, and ²Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA; ³Channing 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
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
How is NDVI Calculated?

\[
\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \\
\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14
\]

Image: NASA

-1 - 0: Dead Plant or Inanimate Object
0 - 0.33: Unhealthy Plant
0.33 - 0.66: Moderately Healthy Plant
0.66 - 1: Very Healthy Plant

Image: Sentera Inc
Greenness and All-Cause Mortality in the Nurse’s Health Study (N=108,630 from 2000-2008)

<table>
<thead>
<tr>
<th>Greenness Quintile</th>
<th>Fully Adjusted HR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenness Quintile 1</td>
<td>Ref</td>
</tr>
<tr>
<td>Greenness Quintile 2</td>
<td>0.92 (0.86, 0.98)</td>
</tr>
<tr>
<td>Greenness Quintile 3</td>
<td>0.90 (0.84, 0.96)</td>
</tr>
<tr>
<td>Greenness Quintile 4</td>
<td>0.94 (0.88, 1.00)</td>
</tr>
<tr>
<td>Greenness Quintile 5</td>
<td>0.88 (0.82, 0.94)</td>
</tr>
</tbody>
</table>

P for Trend 0.002

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

# Cause-Specific Mortality Findings

<table>
<thead>
<tr>
<th>Quintile</th>
<th>Cumulative Average Greenness</th>
<th>Cancer Mortality (3,363 Cases)</th>
<th>Respiratory Mortality (766 Cases)</th>
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<tbody>
<tr>
<td>Quintile 1</td>
<td>Ref</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>Quintile 2</td>
<td>0.93 (0.84, 1.03)</td>
<td>0.84 (0.69, 1.04)</td>
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<tr>
<td>Quintile 3</td>
<td>0.90 (0.81, 1.00)</td>
<td>0.86 (0.69, 1.06)</td>
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<tr>
<td>Quintile 4</td>
<td>0.93 (0.83, 1.03)</td>
<td>0.75 (0.60, 0.94)</td>
<td></td>
</tr>
<tr>
<td>Quintile 5</td>
<td>0.87 (0.78, 0.97)</td>
<td>0.66 (0.52, 0.84)</td>
<td></td>
</tr>
</tbody>
</table>

**P for Trend**

- Cancer Mortality: 0.024
- Respiratory Mortality: <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
Greenness

Total Physical Activity (MET-hrs per Week)

Air Pollution Exposure (Modeled PM$_{2.5}$)

Social Engagement (Participate in Groups >1 / Week)

Mental Health (Doctor-Diagnosed Depression or Antidepressant Use)

Mortality

Greenness

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%)

Total Physical Activity (MET-hrs per Week)  
Proportion Explained: 2.1% (0.2%, 19.3%)

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

1. Health effects of greenness
2. Interrelationships between greenness and air pollution
3. Impacts of greenness and air pollution on health
Multiple Correlated Contextual Factors

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

- a) Satellite PM$_{2.5}$ air pollution levels
- b) NO$_2$ air pollution levels
- c) Greenness
- d) Neighborhood walkability
- e) BMI
- f) Census tract median home
CORRELATED CONTEXTUAL FACTORS

A

Legend
Satellite-based PM2.5 (µg/m³)
4.0 - 6.0
4.1 - 6.0
10.1 - 16.0
11.1 - 14.0

B

Legend
NO2 Weighted Noaest Monitor (ppb)
10 - 12.0
12.1 - 15.0
15.1 - 21.0
21.1 - 35.0

C

Legend
July NDVI
0.38 - 0.44
0.45 - 0.52
0.53 - 0.75
0.76 - 0.98
CORRELATED CONTEXTUAL FACTORS
CORRELATED CONTEXTUAL FACTORS

<table>
<thead>
<tr>
<th></th>
<th>NO2</th>
<th>PM2.5</th>
<th>Greenness</th>
<th>Walkability</th>
<th>Income</th>
<th>Home Value</th>
<th>%No HS</th>
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</thead>
<tbody>
<tr>
<td>NO2</td>
<td>0.43</td>
<td>-0.2</td>
<td>0.31</td>
<td>0.29</td>
<td>0.37</td>
<td>-0.09</td>
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<td>PM2.5</td>
<td>-0.4</td>
<td>0.41</td>
<td>-0.09</td>
<td>-0.16</td>
<td>0.18</td>
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<tr>
<td>Greenness</td>
<td>-0.6</td>
<td>0.37</td>
<td>0.25</td>
<td>-0.37</td>
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<td></td>
<td></td>
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<tr>
<td>Walkability</td>
<td>-0.23</td>
<td>-0.08</td>
<td>0.23</td>
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<tr>
<td>Income</td>
<td></td>
<td></td>
<td></td>
<td>0.83</td>
<td>-0.8</td>
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<tr>
<td>Home Value</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.66</td>
<td></td>
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<tr>
<td>%No HS</td>
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<td></td>
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</tr>
</tbody>
</table>

HS = high school
Healthy Neighborhoods: Walkability and Air Pollution

Julian D. Marshall,¹ Michael Brauer,² and Lawrence D. Frank³

¹Department of Civil Engineering, University of Minnesota, Minneapolis, Minnesota, USA; ²School of Environmental Health, and ³School of Community and Regional Planning, University of British Columbia, Vancouver, British Columbia, Canada
QAIPPE = quintile of adjusted income per person equivalent
Outline

1. Health effects of greenness
2. Interrelationships between greenness and air pollution
3. Impacts of greenness and air pollution on health
~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.
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, c 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
Preventive Effect of Residential Green Space on Infantile Atopic Dermatitis Associated with Prenatal Air Pollution Exposure

Ji-Young Lee¹, Dirga Kumar Lamichhane², Myeongjee Lee¹, Shinhee Ye¹, Jung-Hyun Kwon³, Myung-Sook Park⁴, Hwan-Cheol Kim², Jong-Han Leem², Yun-Chul Hong⁵, Yangho Kim⁶, Mina Ha⁷ and Eunhee Ha¹,*
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

**Green Space ($m^2$) in 100m buffer around Residence**

<table>
<thead>
<tr>
<th></th>
<th>T1 (&lt;11.1)</th>
<th>T2 (11.1-28.8)</th>
<th>T3 (&gt;28.8)</th>
<th>PM$_{10}$</th>
<th>NO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
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</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Odds Ratio (95% CI)**
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, Erica 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

<table>
<thead>
<tr>
<th></th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>NO$_2$</th>
<th>O$_3$</th>
<th>NDVI</th>
<th>Ind. vul.</th>
<th>LC SMR$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td></td>
<td>0.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$</td>
<td>0.37</td>
<td></td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_3$</td>
<td>0.50</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>-0.48</td>
<td>-0.40</td>
<td>0.05*</td>
<td></td>
<td>-0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index of vulnerability</td>
<td>0.26</td>
<td>0.12</td>
<td>-0.44</td>
<td>0.30</td>
<td>-0.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lung cancer SMR</td>
<td>0.16</td>
<td>0.18</td>
<td>0.18</td>
<td>-0.06</td>
<td>-0.07</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>0.46</td>
<td>0.49</td>
<td>0.61</td>
<td>0.07</td>
<td>-0.20</td>
<td>-0.24</td>
<td>0.18</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th></th>
<th>Rural Effect at 5th percentile of NDVI</th>
<th>Rural Effect at 95th percentile of NDVI</th>
<th>Urban Effect at 5th percentile of NDVI</th>
<th>Urban Effect at 95th percentile of NDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{10}$ (5 µg/m$^3$)</td>
<td>1.156</td>
<td>1.129</td>
<td>1.029</td>
<td>1.065*</td>
</tr>
<tr>
<td>PM$_{2.5}$ (2 µg/m$^3$)</td>
<td>1.119</td>
<td>1.098</td>
<td>1.008</td>
<td>1.051*</td>
</tr>
<tr>
<td>NO$_2$ (5 µg/m$^3$)</td>
<td>1.025</td>
<td>1.067*</td>
<td>0.991</td>
<td>1.017*</td>
</tr>
<tr>
<td>O$_3$ (5 µg/m$^3$)</td>
<td>1.082</td>
<td>1.007*</td>
<td>1.018</td>
<td>1.023</td>
</tr>
<tr>
<td>Change in LE</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PM$_{10}$ (5 µg/m$^3$)</td>
<td>-1.81</td>
<td>-1.42*</td>
<td>-0.37</td>
<td>-0.65</td>
</tr>
<tr>
<td>PM$_{2.5}$ (2 µg/m$^3$)</td>
<td>-1.47</td>
<td>-1.01*</td>
<td>-0.13</td>
<td>-0.63*</td>
</tr>
<tr>
<td>NO$_2$ (5 µg/m$^3$)</td>
<td>-0.44</td>
<td>-0.67</td>
<td>0.08</td>
<td>-0.18*</td>
</tr>
<tr>
<td>O$_3$ (5 µg/m$^3$)</td>
<td>-1.02</td>
<td>-0.12*</td>
<td>-0.12</td>
<td>-0.18</td>
</tr>
</tbody>
</table>

* 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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- Peter James
- Trang VoPham
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- Isabel Holland

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- P30 ES000002
- UM1 CA186107
- P01 CA87969
- UM1 CA176726
- K99/R00 CA201542
Thank You!

Questions?