



# Association of residential greenness with obesity and physical activity in a US cohort of women



Paul J. Villeneuve<sup>a,b,\*</sup>, Michael Jerrett<sup>c</sup>, Jason G. Su<sup>d</sup>, Scott Weichenthal<sup>e</sup>, Dale P. Sandler<sup>f</sup>

<sup>a</sup> Department of Health Sciences, Carleton University, Ottawa, ON, Canada

<sup>b</sup> CHAIM Centre, Carleton University, Ottawa, ON, Canada

<sup>c</sup> Fielding School of Public Health, University of California Los Angeles, Los Angeles, CA, USA

<sup>d</sup> School of Public Health, University of California at Berkeley, Berkeley, CA, USA

<sup>e</sup> Department of Epidemiology, Biostatistics, and Occupational Health and Gerald Bronfman Department of Oncology McGill University, Canada

<sup>f</sup> US National Institute of Environmental Health Sciences, RTP, NC, USA

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## ABSTRACT

There is evidence of several health benefits associated with neighborhood greenness, but reasons for this are unclear. Studies have found that those who live in greener neighborhoods are more physically active, and have lower rates of obesity. Relatively few studies have attempted to characterize associations between greenness and both obesity and physical activity concurrently, or among women who are at higher risk of developing cancer and for whom physical activity may be important for primary prevention. To address these gaps, we undertook a cross-sectional analysis of data from 50,884 women who enrolled in the Sister Study between 2003 and 2009. This cohort includes women aged 35–74 whose sister had been diagnosed with breast cancer. Residential measures of greenness were determined using the US National Land Cover database. Logistic regression was used to characterize associations between greenness, obesity, and physical activity. Adjustments were made for other possible confounders. Women who lived in areas with the highest tertile of greenness (based on a 500 m buffer) had a reduced risk of obesity (body mass index (BMI)  $\geq 30$ ) relative to those in the lowest tertile (odds ratio (OR) = 0.83, 95% CI = 0.79–0.87). We also found that those the upper tertile of greenness were 17% more likely to expend more than 67.1 metabolic equivalent (MET) hours per week when compared to those in the lowest tertile (OR = 1.17, 95% CI = 1.10–1.23). Beneficial associations between greenness and both obesity and physical activity were observed in urban and rural areas, and regionally, stronger associations were observed in the western census region in the US. Mediation analyses indicated that physical activity attenuated the association between greenness and obesity by 32%. Our findings indicate that, amongst US adult women at higher risks of breast cancer, residential proximity to greenness may help mitigate against sedentary behaviors that increase the risk of chronic disease.

## 1. Introduction

Obesity is a worldwide pandemic. In 2014, it was estimated that approximately 1.9 billion adults were considered obese (World Health Organization, 2016). The prevalence of obesity in the United States in 2011–2014 was estimated to be 36%, with higher rates among women (38.3%), and women between the ages of 40–59 (42.1%) (Ogden et al., 2015). The public health burden associated with obesity is considerable as excess body mass index (BMI) increases the risk of developing chronic diseases including cancer, heart disease, diabetes, and stroke (World Health Organization, 2016). In 2008, it was estimated that the annual

medical costs associated with obesity in the United States was \$147 billion (Ogden et al., 2015). Increased sedentary behaviors both at work and at home are believed to have played a key role in observed trends in the US and other developed countries, with adults spending an estimated 70% or more of their waking hours sitting (Owen et al., 2010).

Traditionally, epidemiological studies of obesity have focused on the role of individual factors such as physical activity, genetic predisposition, diet, and socio-economic status (Trost et al., 2002). Over the past decade, however, findings from a number of studies suggest that some features of the built environment play an important role in reducing sedentary behaviors, and thereby decreasing obesity. The built

*Abbreviations:* BMI, Body mass index; IRB, Institutional Review Board; MET, Metabolic equivalent; NDVI, Normalized Difference Vegetation Index; NLCD, National Land Cover Database; SES, Socioeconomic status; WHO, World Health Organization

\* Correspondence to: Carleton University Department of Health Sciences, Herzberg Building Room 5410, 1125 Colonel By Drive, Ottawa, ON, Canada K1S 5B6.

E-mail address: [paul.villeneuve@carleton.ca](mailto:paul.villeneuve@carleton.ca) (P.J. Villeneuve).

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environment incorporates the building and transportation design of a city, and includes features such as open green spaces, bike ways/sidewalks, shopping centers, business complexes, and residential accommodation (World Health Organization, 2009). Neighborhoods with greater access to grocery stores, increased walkability, and decreased access to fast food have lower rates of obesity (Frank et al., 2007; Saelens et al., 2003). More recently, women who lived in higher population density counties (i.e., lower sprawl) were found to have lower BMI, and higher rates of physical activity than those who lived in lower density counties (Hruby et al., 2016). Greenness, often referred to as green spaces or natural areas, has been evaluated as a deterrent of obesity largely due to the possibility it provides enhanced opportunities for physical activity (James et al., 2015). Epidemiological investigations in children have somewhat consistently reported an inverse association between the amount of green space and BMI (Dunton et al., 2009; Wolch et al., 2011). However, fewer studies have investigated these associations in adults, and the results have been mixed, varying by age, socio-economic status and the methods used to characterize greenspace (Lachowycz and Jones, 2011). Additionally, few studies have evaluated differences in the strength of the association between urban and non-urban areas.

Studies that have investigated associations between greenness and physical activity have also produced equivocal results with positive associations noted in some (Cohen et al., 2007; Coombes et al., 2010; Mytton et al., 2012), but not in others (Maas et al., 2008; Witten et al., 2008). Interpreting the associations between greenness and obesity and physical activity is complicated by the potential modifying role of socio-demographic status as well as urbanicity. Some studies suggest that access to green spaces, which are often free, or at low cost, have larger benefits among those of lower socio-demographic status (Dadvand et al., 2012; de vries et al., 2003; Mitchell and Popham, 2007, 2008).

While several epidemiological studies have investigated associations between greenspace and obesity and physical activity, few studies have considered both measures. An analysis of 21,832 adults who completed the Danish National Health Interview Survey found that those who lived more than 1 km from green space were less likely to exercise, and more likely to be obese when compared to those who lived less than 300 m (Toftager et al., 2011). In contrast, a survey of 3883 adults in 85 neighborhoods in Ottawa, Canada found that those who lived in greener neighborhoods were less likely to exercise, and had increased rates of obesity in men while reduced rates in women (Prince et al., 2011). The findings from these two studies may have been influenced by biases introduced by characterizing green spaces using self-reported data (Toftager et al., 2011), or at an ecological (neighborhood) level (Prince et al., 2011).

Exposure measurement error resulting from the characterization of greenness in epidemiological studies, may have contributed to the inconsistent associations with physical activity and obesity. To date, most studies have relied on self-reported measures of greenness, or the Normalized Difference Vegetation Index (NDVI) (James et al., 2015). The NDVI is the most widely used measure of vegetation and is derived using satellite imagery that can describe vegetative density at a high spatial resolution (~30 m) worldwide. Although the NDVI is an objective measure of greenness, it is only able to capture the amount of vegetation in a given area and is not capable of providing qualitative information about the usability, or access. For these reasons, some have recommended that epidemiological studies adopt metrics that are better able to differentiate between these features of greenness (James et al., 2015; Lee and Maheswaran, 2011).

Here, we characterized associations between residentially-based measures of greenness and both obesity and physical activity in a national US survey of women at higher risk of developing breast cancer. Our measures of greenness are based on the National Land Cover Database that is better able to differentiate between features of greenness than the NDVI. Further, we explored to what extent socio-demographic status, age and place of residence (i.e., urban, suburban, rural) modified associations between greenness and sedentary behaviors.

Lastly, we examined to what extent physical activity mediated associations between greenness and obesity.

## 2. Materials and methods

### 2.1. Study population

The study population consisted of women in the Sister Study, a U.S. nationwide study designed to evaluate environmental and genetic risk factors of breast cancer (US National Institutes of Environmental Health Sciences, 2017). Approximately fifty thousand initially breast cancer-free women, ages 35–74, who had a sister previously diagnosed with breast cancer, were enrolled in the study between August 2003 and July 2009. Participants were from throughout the US, including Puerto Rico. At baseline, participants completed computer assisted telephone interviews that collected data on demographic characteristics, environmental exposures, lifestyle factors including physical activity, medical history, and other possible risk factors for breast cancer. In addition, participants provided their residential histories and self-reported measures of physical activity during childhood and in the past 12 months.

The main and secondary places of residence at the time of enrollment were collected from the participants and this yielded 53,374 records for the 50,884 enrolled women. These addresses were geocoded to assign residential measures of greenness. An exact address was available for 50,746 (95.1%) of these residences, while the nearest intersection and zip code were used for the remaining 4.6%, and 0.4% of the addresses, respectively. We further restricted assignment of green spaces to those residences (n = 51,990) that were based in the contiguous US. We further restricted the analysis to a single residential address per participant, using the address given as main place of residence (n = 49,649). For these residences, participants indicated whether they were in urban, suburban, rural or in a small town. In addition, residential address was linked to census data to obtain the census region, division, and census tract population for each participant (US Census Bureau, 2017).

All participants provided written informed consent. The Sister Study was approved by the Institutional Review Board (IRB) of the National Institute of Environmental Health Sciences, National Institutes of Health, and the Copernicus Group IRB.

### 2.2. Exposure to greenness

The US National Land Cover Database (NLCD) was used to assign residential measures of greenness. Land cover describes the presence (or absence) of vegetation on the land surface. We downloaded data from the Multi-Resolution Land Characteristics Consortium for 2006, and 2011. The NLCD in these years used a 20-class land-cover classification scheme that has been applied consistently across the US at a resolution of 30 m based on a decision-tree classification of respective circa 2006 and 2011 Landsat satellite data (Homer et al., 2015). These 20 classes span 8 broader land cover categories have been previously described, and are listed in Appendix Table 1 (Multi-Resolution Land Characteristics Consortium, 2016). Since the primary aim of this research was to describe associations of residential greenness with obesity and physical activity, we created the following exposure metrics and assigned them to the geocoded home addresses of the Sister Study participants:

Number	Exposure metric	Land cover classes (NLCD values in parentheses)
1	<i>Green1</i>	Includes the forest (values:41,42,43), shrubland (52), and herbaceous (71,72, 73) land covers
2	<i>Green2</i>	Includes classes within <i>Green1</i> as well as developed open spaces (21)

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