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Residential greenness and adiposity: Findings from the UK Biobank

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ABSTRACT

Background: With the rapid urbanization and prevailing obesity pandemic, the role of residential green exposures in obesity prevention has gained renewed focus. The study investigated the effects of residential green exposures on adiposity using a large and diverse population sample drawn from the UK Biobank.

Materials and methods: This was a population based cross-sectional study of 333,183 participants aged 38–73 years with individual-level data on residential greenness and built environment exposures. Residential greenness was assessed through 0.50-metre resolution normalized difference vegetation index (NDVI) derived from spectral reflectance measurements in remotely sensed colour infrared data and measured around geocoded participants' dwelling. A series of continuous and binary outcome models examined the associations between residential greenness and markers of adiposity, expressed as body-mass index (BMI) in kg/m^2, waist circumference (WC) in cm, whole body fat (WBF) in kg and obesity (BMI $\geq$ 30 kg/m^2) after adjusting for other activity-influencing built environment and individual-level confounders. Sensitivity analyses involved studying effect modification by gender, age, urbanicity and SES as well as examining relationships between residential greenness and active travel behaviour.

Results: Residential greenness was independently and consistently associated with lower adiposity, the association being robust to adjustments. An interquartile increment in NDVI greenness was associated with lower BMI ($\beta_{BMI} = -0.123$ kg/m^2, 95% CI: -0.14, -0.10 kg/m^2), WC ($\beta_{WC} = -0.551$ cm, 95% CI: -0.61, -0.50 cm), and WBF ($\beta_{WBF} = -0.138$ kg, 95% CI: -0.18, -0.10 kg) as well as a reduced relative risk of obesity (RR = 0.968, 95% CI: 0.96, 0.98). Residential greenness was beneficially related with active travel, being associated with higher odds of using active mode for non-work travel (OR = 1.093, 95% CI: 1.08, 1.11) as well as doing > 30 min walking (OR = 1.039, 95% CI: 1.03, 1.05).

Conclusion: Residing in greener areas was associated with healthy weight outcomes possibly through a physical activity-related mechanism. Green allocation and design may act as upstream-level public health interventions ameliorating the negative health externalities of obesogenic urban environments. Further prospective studies are needed to identify potential causal pathways and thereby effectively guide such interventions.

1. Introduction

Obesity is a global pandemic (Swinburn et al., 2011). Excessive adiposity is an important risk factor for morbidity and mortality from type 2 diabetes, cardiovascular disease and cancer (Flegal et al., 2007; Bhaskaran et al., 2014; Tobias et al., 2014). The role of built environment has long been established, especially in shaping daily lifestyles, walking, activity behaviours and adiposity outcomes (Brownson et al., 2009; Leal and Chaix, 2011; Sallis et al., 2012; Sarkar et al., 2014). Residential green spaces, in particular, constitute a key health-promoting component of built environment (Depledge et al., 2011; Hartig et al., 2014). Exposures to residential green has been independently associated with higher levels of recreational and utilitarian walking and physical activity (Bedimo-Rung et al., 2005), lower odds of obesity (Lachowycz and Jones, 2011), higher levels of social contacts and sense of community (Kweon et al., 1998). It has also been established to ameliorate adverse effects originating from exposures to air pollution (Nowak et al., 2006) and urban heat island effects (Loughner et al., 2012).

There is nonetheless some ambiguity in the relationships between residential greenness and physical activity and obesity and research evidence has been far from consistent. A recent systematic review (James et al., 2015) of twenty five cross sectional studies has reported intermediate-level evidence on the beneficial effects of residential greenness upon obesity. However, a few null (Potestio et al., 2009; Mowafi et al., 2012; Ord et al., 2013) and counterintuitive (Maas et al., 2008; Prince et al., 2011; Cummins and Fagg, 2012) findings were also noted. Additionally, it is often difficult to establish the exact functional causality as most studies have focused on the protective effects of residential greenness outcomes accrued from their functional role as

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recreational spaces, often measured in terms of size, density and accessibility to residential park space. There have thus far been very few studies on the links between the functional role of residential green as *salutogenic environmental spaces* and adiposity (Sarkar et al., 2015b). Furthermore, many of the studies measure residential green space at an aggregate level of analysis such as census-defined units or through satellite-derived metrics of lower spatial resolution, while most have been small scale studies within homogeneous environmental settings, thereby limiting accuracy, statistical reliability and generalizability.

The present study examines the links between adiposity and residential greenness in a large and diverse UK-wide adult population employing data from the UK Biobank cohort and high resolution metrics of salutogenic green exposures after adjusting for other pertinent activity-influencing built environment, socio-demographics, lifestyle and co-morbidities. Effect modification by gender, age, urbanicity and SES was also tested.

2. Materials and methods

2.1. Study sample

The UK Biobank is a prospective population-based cohort of 502,649 adults aged 37–73 years (99.5% aged between 40 and 69 years) established to study the lifestyle, environment and genetic determinants of a various adult diseases. The participants recruited at baseline (2006–2010) attended one of the 22 collection centres across UK for detailed assessment providing a range of information through extensive questionnaires on socio-demographics, lifestyle and medical history; anthropometric measurements; biological samples (blood, urine and saliva); imaging and hospital-related outcomes. Details of the study can be found elsewhere (Allen et al., 2014; Sudlow et al., 2015). The recruited participants resided within 25 miles of the collection centres and included participants residing in urban areas as well as some beyond the urban fringes (Fig. 1). Built environment exposures within multi-scale residential neighbourhoods were modelled for the cohort participants. The cross sectional study employed N = 353,670 (70.4%) participants of the UK Biobank with valid data on residential green exposures. After exclusions on account of incomplete data on adiposity and individual-level confounders for 18,438 (3.7%), and built environment and air pollution exposure variables for 2049 (0.4%) participants, an analytic sample of N = 333,183 was available for analyses.

2.2. Adiposity measures

Body mass index (BMI), waist circumference (WC), whole body fat (WBF) and obesity constituted the primary measures of adiposity. Standing height (cm) was measured using a Seca 202 device and waist circumference (cm) was enumerated using a Wessex non-stretchable sprung tape. Weight and whole body fat mass was measured using electrical bio-impedance with the Tanita BC-418 MA body composition analyser. Body mass index (BMI) was derived by dividing weight (kilograms) by square of standing height (square metres). Obesity was expressed as per as the World Health Organization's definition (cut-offs for BMI ≥ 30 kg/m^2). Anthropometrics were assessed by trained technicians at the collection centres as the participants wore light clothes and no shoes.

2.3. Active travel behaviour

Using active travel mode and doing > 30 min walking were employed as secondary outcome variables of active travel behaviour. The UK Biobank participants were asked "In the last 4 weeks, which forms of transport have you used most often to get about? (Not including any journeys to and from work)" with the option of selecting one or more of the following: car/motor vehicle; walk; public transport; cycle. This was subsequently dichotomized into a binary variable; using active travel mode (walk, cycle, public transport) versus motorized transport (car/motor vehicle). The questionnaire on "average number of minutes spent walking on a typical day" was transformed in to a binary variable (doing > 30 min walking versus doing < 30 min).

2.4. Environmental exposures

Data on residential environment exposures were obtained from the UK Biobank Urban Morphometric Platform (UKBUMP). The UKBUMP is a linked database of objectively measured urban morphological metrics measuring health-influencing environmental exposures within functional neighbourhoods around UK Biobank participants' geocoded dwelling locations (Sarkar et al., 2015a; Sarkar and Webster, 2017). Spatial and network analyses were performed upon diverse national-level spatial databases resulting in the automation of multiple health-specific neighbourhood metrics categorized as density, destination accessibility, street-level physical accessibility, food outlets accessibility, building class, greenness, terrain and neighbourhood deprivation. These exposure metrics have been subsequently linked back to the anonymized UK Biobank participant ids. Briefly, participant's dwelling addresses were first geocoded to the level of building footprints and dwelling neighbourhoods was defined within street network buffers centred on the geocoded locations in ArcGIS12 Network Analyst. Accurate data on building-level land uses and street networks were sourced from UK Ordnance Survey AddressBase Premium and MasterMap Integrated Transport Network databases. The UK-wide AddressBase Premium data of Ordnance Survey comprised approximately 36 million valid address point features with approximately 550 different land use classifications. UKBUMP employed standard land-use classification scheme of the Ordnance Survey AddressBase Premium database and has land-use intensities of > 200 health promoting/inhibiting land-use destinations within the defined dwelling neighbourhoods as well as measures of street distances to the nearest, street network based measures of walkability. Residential greenness was modelled from a 0.50-metre colour infrared imagery.

2.4.1. Residential greenness

Residential exposure to salutogenic green environment was measured with the help of normalized difference vegetation index (NDVI). The NDVI is an objective measure of overall salutogenic green exposure showing a strong correlation with expert's ratings in epidemiological research setting (Rhew et al., 2011) and has been employed in previous studies on links between green exposure and walkability (Sarkar et al., 2015b), physical activity (Almanza et al., 2012; Gong et al., 2014; McMorris et al., 2015) and adiposity (Bell et al., 2008; Pereira et al., 2013; Dadvand et al., 2014). It is a unit-less index of relative overall green vegetation or biomass derived from pixel values of spectral reflectance in remotely sensed data. The underlying principle employed in the NDVI calculation is that chlorophyll in healthy vegetation absorb radiation in the visible red region (630–690 nm) of the electromagnetic spectrum and reflect radiation in the near-infrared region (760–900 nm). This differential absorbance and reflectance wavelengths by chlorophyll is employed as a proxy for green quality and intensity, as illustrated by the following formulae:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

where RED and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions of the electromagnetic spectrum. Index scores range between − 1 to + 1 with high negative values indicating water, those in the range 0–0.1 representing barren rock, sand or snow, 0.2–0.3 corresponding to shrub and grassland, while higher values indicating dense green vegetation.

A series of 0.50 cm by 0.50 cm resolution colour infrared (CIR) imagery collected by Bluesky through specially developed sensors