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The relationship between neighbourhood tree canopy cover and heat-related ambulance calls during extreme heat events in Toronto, Canada

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ABSTRACT

Two thirds of Canadians reside in urban areas and 85% of recent population growth occurs in these areas. The intensity and duration of extreme hot weather events are predicted to increase in Canadian cities and in cities globally. It is well established that human suffering due to extreme heat is exacerbated in urban as compared to rural environments. Understanding the characteristics of urban landscapes that play the greatest roles in exacerbating the human health impact of extreme heat is thus imperative. This study explores the relationship between the amount of canopy cover from trees and the incidence of heat-related morbidity during extreme heat events in 544 neighbourhoods of Toronto, Ontario, Canada. Four extreme heat events from three years were studied. Heat-related ambulance calls were found to be 12.3% higher during the heat events than in the preceding or the following week. The number of heat-related ambulance calls was negatively correlated to canopy cover (Spearman Rank rho = −0.094, p = 0.029) and positively correlated to hard surface cover (Spearman Rank rho = 0.150, p < 0.001). Toronto neighbourhoods, as defined by Census Tracts, with less than 5% canopy cover had approximately five times as many heat-related calls as those with greater than 5% tree canopy cover, and nearly fifteen times as many heat-related calls as Census Tracts with greater than 70% tree canopy cover. These data suggest that even a marginal increase in the tree canopy cover from <5% to >5% could reduce heat-related ambulance calls by approximately 80%. These results have important implications for human health during heat events, particularly in the context of global climate change and urban heat islands, both of which are trending toward hotter urban environments in future.

1. Introduction

Between 2006 and 2011, 85% of population growth in Canada (1,589,378 people) occurred in urban areas (i.e. population >100,000) and these areas accounted for 69% of the total population (23,123,441 people) as of May 2011 (Statistics Canada, 2012b). The elevated rates of heat-related morbidity and mortality associated with urban, as compared to rural, environments (Smoyer et al., 2000; Luber and McGeehin, 2008; Canadian Institute for Health Information, 2011) provide a link between urbanization and human heat health.

Toronto, Ontario is Canada's largest city and also experiences the nation's highest frequency of extreme heat events (EHEs, also known as "heat waves") lasting two days or longer (Smoyer-Tomic et al., 2003). The frequency of EHEs is predicted to triple between 2005 and 2050 (Toronto Public Health, 2005; Environment Canada, 2005) and to quadruple by 2080 (Toronto Public Health, 2005). To date, the specific characteristics of Toronto's complex urban landscape that may play a role in human health impact of extreme heat have not been identified.

Exposure to extreme and/or prolonged heat can result in heat-related morbidity, which manifests as heat edema, heat rash (miliaria rubra), heat cramps, heat fainting (parade syncope), heat exhaustion, and/or heat stroke (Centers for Disease Control, 2006; Toronto Public Health, 2009b; Health Canada, 2011). If untreated,

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damage to various internal organs, coma, and death can result (Centers for Disease Control, 2006; Luber and McGeehin, 2008; Toronto Public Health, 2009b). Morbidity (Semenza et al., 1999; Bassil et al., 2009; Bassil et al., 2011; Vanos et al., 2012a; Hartz et al., 2013) and mortality (Semenza et al., 1996; Smoyer et al., 2000; Toronto Public Health, 2005; Centers for Disease Control, 2006; Pengelly et al., 2007; Robine et al., 2008) specifically related to heat exposure have been reported in temperate regions across Europe and North America, including Toronto. Hartz et al. (2013) compared heat-related morbidity in Chicago, IL (temperate) and Phoenix, AZ (hot, arid). Larger spikes of heat-related morbidity occurred in Chicago as compared to steadier occurrences Phoenix, suggesting a degree of acclimatization in hot, arid environments that is not realised in more temperate regions (Hartz et al., 2013). From 1954–2000, 120 deaths per year in Toronto alone were attributed to heat exposure, a number that is expected to triple by the year 2080 (Toronto Public Health, 2005). Canada's urban-centric population and predictions of both increased EHE frequency and heat-related illness collectively support the need for improved understanding of the impacts of extreme heat and the urban landscape on human health.

Urbanization has resulted in significant modification of natural landscapes through the intensification of urban development—a change that has consequences for the regional climate and those living within the built environment (Georgescu et al., 2014). "Urban heat islands" (UHIs) describe the relatively greater temperatures of highly built urban environments versus rural areas (Oke, 1987; Luber and McGeehin, 2008; Stewart and Oke, 2009; Mohsin and Gough, 2010; Canadian Institute for Health Information, 2011). Urban heat islands commonly form in large built-up urban environments due to the high heat capacity of buildings and urban surfaces, as well as long wave radiation that is trapped and emitted by tall buildings, thus preventing heat loss from the urban canopy layer (Oke et al., 1991). This trapped heat causes the overheating of built features in urban landscapes and creates thermal discomfort and heat stress in humans populating these areas (Vanos et al., 2010).

Urban surface and air temperatures are intrinsically connected to many interrelated urban design features such as material use, landscape and building surface properties, orientation, sky view factor, and sun angle (Krayenhoff and Voogt, 2007; Yaghoobian et al., 2010; Ketterer and Matzarakis, 2014). The selection of surface cover (e.g., asphalt versus vegetation, trees versus open space design) tightly controls the resulting surface temperature and thus the overlying air temperature (Shashua-Bar et al., 2011) as well as canopy temperature when trees are present (Yaghoobian et al., 2010). Overheating and the significant variations of temperatures across a city are especially relevant during summertime EHEs (Harlan et al., 2006; Jenerette et al., 2011). On sunny, warm days, the exposure of the surface and humans to the mean radiant temperature – the combination of all short- and long-wave radiant fluxes (Thorsson et al., 2007) – becomes the most significant agent of heat gain (Johansson et al., 2014).

Open, un-shaded parks with high radiant heat loads are less conducive spaces for safe physical activity and thermal comfort (Matzarakis and Endler, 2010; Vanos et al., 2012a). Hence, the design choice of an urban area can either support or diminish the long-term health and resilience of a city and its inhabitants. Specific heat-health vulnerabilities are often present in high-density urban neighbourhoods that lack open space and vegetation (Harlan et al., 2006; Stewart and Oke, 2012; Vanos, 2015). For example, Harlan et al. (2006) found that lower income and minority populations in Phoenix, AZ lived in warmer neighbourhoods that were crowded and had little greenspace. These residents were also exposed to corresponding health risks of high temperature exposure.

Elevated frequencies of total ambulance calls (Dolney and Sheridan, 2006) and, more specifically, of heat-related ambulance calls (Bassil et al., 2009) have been reported within certain areas of Toronto during hot weather. Recreational waterfront areas along Lake Ontario, large rail yards, low-income inner-city neighbourhoods, and areas with a high-density of homelessness report the highest incidences of heat-related morbidity in Toronto (Dolney and Sheridan, 2006; Bassil et al., 2009). In order to better understand the influence of distinct landscape characteristics on human health during EHEs, a more detailed characterization of high-risk urban landscapes and of specific landscape characteristics that influence human heat health is warranted. Accordingly, the goal of the proposed study is to examine, at the relatively fine spatial scale of the Census Tract (CT), the relationship between tree canopy coverage and heat-related morbidity during extreme heat events in Toronto, Canada.

2. Methods

2.1. Study area

The study area was the City of Toronto, Ontario, Canada (+43.7182°, −79.3774°; ~63,421 ha; ~2,615,000 population). The most recent national census (2011) divided Toronto into 544 CTs, which are defined as small areas with a relatively stable and socioeconomically homogeneous population between 2500 and 8000 (Statistics Canada, 2012a). Census Tracts were chosen as the areal unit for analysis since the relatively stable population between CTs limited the influence of changes in population on the results (e.g. heat-related ambulance calls). Finer-scale areal units (e.g. Dissemination Areas or Dissemination Blocks) were not used since greater numbers of these units within the City of Toronto (3685 Dissemination Areas and 12,896 Dissemination Blocks) would be more cumbersome for analysis, the population is not stable between Dissemination Blocks, and using the smaller units would have resulted in more units with no heat-related ambulance calls. Further, using CTs as the areal unit provided a relatively fine spatial scale for analysis as compared to previous studies that examined heat-related morbidity and mortality either across the single areal unit of the City of Toronto (Smoyer et al., 2000; Pengelly et al., 2007; Bassil et al., 2008, 2011; Vanos et al., 2012a) or within coarser-scale areal units (Bassil et al., 2009). Mean CT area was 116.6 ± 146.0 ha (range: 1.3–2023.3 ha).

Study Period Selection

Four EHEs were selected for the present study from the historical pool (2001–2011) of days officially classified as either Heat Alert (HA) and Extreme Heat Alert (EHA) days by Toronto Public Health (Toronto Public Health, 2012). HA/EHA are called in Toronto when a "hot air mass is forecast and the likelihood of deaths is more than 65/90 percent", respectively (Toronto Public Health, 2009a). Rather than basing event classification on meteorological factors alone (e.g. maximum daily air temperature (T_{max}) or indices such as the apparent temperature or Humidex), the HA/EHA approach uses the Spatial Synoptic Classification system, which focuses on human health and well-being (Sheridan and Kalkstein, 2004). The four EHEs that best satisfied the predetermined selection criteria (Table 1) were selected for the present study: 27–30 June, 2005; 29 July–2 August, 2006; 24–27 May, 2010; and 29 August–2 September, 2010 (n = 18 EHE days). Buffer periods of seven days before (Pre) and after (Post) each EHE were also examined. A total of five days (25 June, 2005; 26–27 July, 2006; 30–31 May, 2010) from the Pre and Post periods were classified as HA by Toronto Public Health (Toronto Public Health, 2012) and therefore removed from all analyses. The remaining Pre (n = 25) and Post (n = 26) days were used for this study. Heat-related morbidity was assessed based on the current day numbers (lag 0). Although heat-related mortality from all causes appears to peak with a one- to three-day lag following high temperatures (Semenza et al., 1996; Anderson and Bell,