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Assessing inequities in active transportation: Does the effect of walkable built environments vary according to neighbourhood socioeconomic status?

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Cette thèse intitulée:

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Résumé

Certains chercheurs veulent que les gouvernements modifient les déterminants de l'environnement urbain du transport actif dans des régions à bas statut socioéconomique pour réduire les inégalités en activité physique et santé. Mais, des individus de différents sous-groupes de la population pourraient réagir différemment à l'environnement urbain. Plusieurs chercheurs ont examiné si l'influence d'un environnement urbain propice aux piétons sur le transport actif diffère entre les personnes ayant un statut socioéconomique de quartier différent et ont obtenu des résultats mixtes. Ces résultats équivoques pourraient être dus à la façon dont les mesures de l'environnement urbain étaient déterminées. Plus spécifiquement, la plupart des études ont examiné l'effet de la propicité à la marche des lieux résidentiels et n'ont pas pris en compte les destinations non-résidentielles dans leurs mesures. Cette étude a examiné le statut socioéconomique du quartier comme modérateur de la relation entre l'environnement urbain et le transport actif en utilisant des mesures d'environnement urbain qui proviennent de toute la trajectoire spatiale estimé des individus. Les trois variables de l'environnement urbain, la connectivité, la densité des commerces et services et la diversité du territoire avaient une plus grande influence sur le transport actif de ceux avec un haut statut socioéconomique. Nos résultats suggèrent que même quand la configuration de l'environnement urbain est favorable pour le transport actif, il peut y avoir des barrières sociales ou physiques qui empêchent les gens qui habitent dans un quartier à bas statut socioéconomique de bénéficier d'un environnement urbain favorable au transport actif.

Mots-clés : Transport actif, statut socioéconomique, propicité à la marche, environnement urbain, connectivité, densité des destinations, diversité de territoire

Abstract

Researchers have called for policymakers to modify the built environment determinants of active travel in low SES areas in the hopes of reducing disparities in physical activity and health. However, different population sub-groups may be differently responsive to the built environment. Researchers have examined whether the influence of walkable built environments on active transportation differs for those of different socio-economic status and have obtained mixed results. These equivocal findings could be due to the way the built environment measures were determined. More specifically, most studies have examined walkability in residential settings ignoring non-residential destinations. This study examined socio-economic status as a moderator of the relationship between the built environment and active transportation using a trip level analyses with measures of built environment exposure derived from the estimated spatial trajectory of transport trips. All three of the environmental variables, connectivity, density of business and services, and land-use mix, were found to have a greater association with AT if the individual undergoing the trip was from a high socioeconomic status neighbourhood. Our findings suggest that even when the built environment is favourable for AT there may be social or physical barriers that prevent those from low socio-economic status neighbourhoods from benefitting from built environments that are conducive to active transportation.

Keywords : active transportation, socioeconomic status, walkable, built environment, connectivity, density of destination, land-use mix

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SES: Socioeconomic status

AT : Active transportation

To my family, friends and loved ones,
whose love and support inspires me to fulfill my dreams.

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Introduction

1.1 Health consequences of physical inactivity

Physical inactivity is one of the most pressing health challenges of the 21st century (De Nazelle et al., 2011) as it is a well-known determinant of multiple chronic diseases, causes of death, and disability (Bull et al., 2004). According to the world health organization physical inactivity on its own accounts for 3.2 million deaths annually and is the cause of 19 million disability-adjusted life years (DALYs). It is estimated that physical inactivity can explain 21.5% of coronary heart disease cases, 11% of ischemic stroke cases, 14% of diabetes cases, 16% of colon cancer cases and 10% of breast cancer cases worldwide (Bull et al., 2004). It has also contributed to the overweight and obesity epidemic that accounts for 2.8 million deaths a year (WHO, 2009).

1.2 Inequalities in disease and physical activity

Equity in health may be defined as: "the absence of systematic disparities in health (or in the major social determinants of health) between social groups who have different levels of underlying social advantage/disadvantage—that is, different positions in a social hierarchy" (Braveman & Gruskin, 2003). Research consistently indicates that the level of engagement in multiple types of physical activity, a major determinant of health, differs according to socio-economic status (Ford et al., 1991; Giles-Corti & Donovan, 2002b; Van Lenthe, Brug, & Mackenbach, 2005; Van Tuyckom & Scheerder, 2010; Yen & Kaplan, 1998). The social stratification of physical activity may play a key role in explaining SES gradients in health (Beenackers et al., 2012; Berrigan, Troiano, McNeel, DiSogra, & Ballard-Barbash, 2006; Van Tuyckom & Scheerder, 2010). Living in a socio-economically disadvantaged neighbourhood has been associated with increased incidence of coronary heart disease (Roux et al., 2001), stroke (P. Brown, Guy, & Broad, 2005), diabetes (P. Brown et al., 2005), obesity (P. Brown et al., 2005; Roux et al., 2001), and cancer (Du et al., 2007; Marcella & Miller, 2001; Ward et al., 2004) all of which are health effects of physical inactivity.

The majority of studies that have examined the social stratification of physical activity have focused on leisure time physical activity and have demonstrated that those from high SES groups engage in more leisure time exercise (Turrell, Hewitt, Haynes, Nathan, & Giles-Corti, 2014) and are therefore more likely to meet recommended levels of physical activity (Giles-Corti & Donovan, 2002b). Although less dominant in the literature, studies also report stratification in occupational, household, and transport related physical activity. Compared to the most advantaged those living in the least advantaged neighbourhoods have been found to be less likely to engage in leisure time walking, cycling, and gardening, less likely to participate in sports activities but more likely to engage in walking and cycling for transportation (Van Lenthe et al., 2005).

There is a growing interest in determining the types of programs and policies that may reduce the disproportionate burden of illness of the impoverished (Adler, Boyce, Chesney, Folkman, & Syme, 1993; Marmot & Bell, 2012; Mitchell & Popham, 2008) such as interventions to increase physical activity. Traditionally, public health promotion efforts have concentrated their efforts on encouraging leisure time physical activity (Bull et al., 2004; Colley et al., 2011). Despite these efforts, studies still find that those of low SES engage in insufficient recreational physical exercise to meet recommended physical activity guidelines (Giles-Corti & Donovan, 2002b). Research has shown that even when those of low SES have superior access to recreational facilities, they are less likely to engage in recreational physical exercise than those of higher income (Giles-Corti & Donovan, 2002b). In fact, although proximity to recreational facilities may encourage participation in sports (Giles-Corti & Donovan, 2002a), barriers such as costs and time may prevent those from disadvantaged communities from engaging in recreational physical exercise (Cora Lynn Craig, Cameron, Russell, & Beaulieu, 2001; Lovasi, Hutson, Guerra, & Neckerman, 2009).

Public health promotion efforts to encourage AT have been suggested as an alternative to programs promoting recreational exercise in low SES groups. As compared to recreational physical activity, AT may be more likely to be adopted as a means of exercise by individuals from low SES groups, since AT is inexpensive, requires no special facilities (Hillsdon & Thorogood, 1996), and can easily be integrated into the daily routine (Moudon & Lee, 2003).

1.3 Active transportation: definition and trends

AT is a form of physical activity, as it consists of using active means of travel (ex: walking, biking) that result in energy expenditure (Pabayo, 2010). European countries such as Germany, Sweden, Belgium, and the Netherlands tend to have rates of AT that are at least twice as great as the rates of North American countries such as the United-States and Canada (Buehler & Pucher, 2012; Hallal et al., 2012). According to the 2011 Canadian census, only 5.7% of commuters walked to their workplace and 1.3% cycled to work (Statistics Canada, 2011). In Montreal, the most recent origin-destination survey results indicate that AT is undertaken for only 10% of trips (AMT, 2013). The number of AT trips increased an average of 2% annually between 2003-2008 (AMT, 2008) and by 1.8% between 2008 and 2013 (AMT, 2013).

1.4 Narrowing the gap in physical activity

Low socio-economic status is often associated with a higher prevalence of walking and cycling for transport (Adams, 2010; Giles-Corti & Donovan, 2002b; Goodman, 2013; Miles, Panton, Jang, & Haymes, 2008; Owen et al., 2007; Pliakas, Wilkinson, & Tonne, 2014; Turrell, Haynes, Wilson, & Giles-Corti, 2013; Turrell et al., 2014; Van Dyck et al., 2010; Van Lenthe et al., 2005). Thus, it has been hypothesized that higher levels of active transportation (AT) amongst disadvantaged populations may offset their low levels of recreational physical activity (Turrell et al., 2013). However, accounting for current rates of AT related exercise decreases but does not extinguish this gradient in physical activity (Berrigan et al., 2006; Giles-Corti & Donovan, 2002b). Given the popularity of AT amongst disadvantaged communities, implementing health promotion efforts to induce further increases in AT in low SES communities may be an effective way of diminishing health disparities (Turrell et al., 2013).

There has been a movement in the literature to unearth the environmental influences that act as key determinants of AT including the characteristics of walkable environments (environments that promote walking and cycling) (B. Saelens, Sallis, & Frank, 2003; Sallis, Frank, Saelens, & Kraft, 2004; Sugiyama, Neuhaus, Cole, Giles-Corti, & Owen, 2012). This research suggests that interventions that aim to increase AT are likely to be ineffective in the absence of walkable built environments.

Disadvantaged groups are often more likely to live in areas with poor neighbourhood design (L. D. Frank, Kerr, Sallis, Miles, & Chapman, 2008; Sallis et al., 2011; Van Lenthe et al., 2005) and therefore may have a lower exposure to walkable neighbourhoods. Interventions that modify the built environment to create walkable environments in low SES areas have the potential to induce widespread population level increases in physical activity (Turrell et al., 2013; Van Dyck et al., 2010), subsequently reducing health disparities (Sallis et al., 2011). However, research has demonstrated that different population sub-groups may be differentially responsive to the built environment (Sallis et al., 2011). If walkable built environments have a lesser influence on the AT of low SES individuals, then modifying the built environment determinants of active travel in low SES areas could be an ineffective method of reducing health disparities. Before practitioners implement interventions to modify the built environment, it is important to first determine if walkable built environments equally influence the AT of those of high and low SES.

Literature review

The following literature review provides a rationale for examining if walkable built environments equally influence the AT of those of high and low SES. In this review, we first describe the benefits of AT. Secondly, we describe its correlates. Thirdly, we examine the research on the environmental determinants of active travel. Specifically, we discuss the research that has been conducted on the environmental determinants: connectivity, land-use mix and access to destinations. Fourthly, we examine previous research that has been conducted to determine if individuals living in low SES neighbourhoods benefit as much as those from high SES neighbourhoods from features of the built environment that promote AT. Finally, we delve into the literature to discuss the developments in the theory and methods used for measuring exposure in the field of contextual effects research.

2.1 Benefits of active transportation

2.1.1 *Health benefits of active transportation*

Engaging in regular physical activity is a widely accepted method of disease prevention. A dose-response relationship exists between physical activity and health benefits, whereby increases in physical activity result in greater health benefits (Tremblay et al., 2011; Warburton, Charlesworth, Ivey, Nettlefold, & Bredin, 2010). Thus, frequent daily physical activity is paramount for maintaining physical and mental health.

Engaging in AT is an effective method of integrating physical exercise in the daily routine. AT can generate individual health benefits by increasing physical activity levels in active travellers, thereby reducing individual risk of obesity, diabetes, cardiovascular mortality, coronary heart disease, stroke, hypertension (Hamer & Chida, 2008; Pucher, Buehler, Bassett, & Dannenberg, 2010) and all-cause mortality (Andersen, Schnohr, Schroll, & Hein, 2000; Barengo et al., 2004). Furthermore, physical activity accumulated through small bouts such as AT can elicit similar or greater health benefits than longer sessions of continuous exercise (Hamer & Chida, 2008; Murphy, Blair, & Murtagh, 2009; Murphy, Nevill, Neville, Biddle, & Hardman, 2002; Park, Rink, & Wallace, 2006).

Replacing vehicular trips by AT can decrease air pollution and noise pollution (L. D. Frank et al., 2006). Taking AT can decreases personal air pollutant exposure (Giles-Corti, Foster, Shilton, & Falconer, 2010); drivers have greater exposure to airborne pollutants compared to those outside the vehicle even compared to those cycling in heavy traffic. For example, drivers can be exposed to 2-4 times greater concentrations of air pollutants such as BTEX and particulate matter than bicyclists (Rank, Folke, & Jespersen, 2001). AT can also decrease population level exposure to air pollution. Vehicle miles travelled is positively associated with concentrations of pollutants such as oxide of nitrogen and volatile organic compounds, which react in the light to produce ozone (L. D. Frank et al., 2006). This air pollution increases population risk of contracting both respiratory diseases (L. D. Frank et al., 2006; Giles-Corti et al., 2010) and cardiovascular diseases (Brook et al., 2010).

Increasing AT can also reduce population level exposure to noise pollution by instigating a reduction in heavy traffic. Traffic is a common cause of chronic noise exposure, which may lead to raised blood pressure, annoyance and high stress levels. Chronic noise pollution has also been shown to affect cognitive function in children by triggering poor concentration, poor memory, poor auditory discrimination, and poor performance in school (Stansfeld & Matheson, 2003).

2.1.2 *Economic benefits of active transportation*

Increasing global levels of physical activity through means of AT could also generate significant economic benefits. For example, the overall 2009 annual economic burden of physical inactivity in Canada was estimated at 6.8 billion dollars, a significant proportion of health care expenditure (3.8%) (Janssen, 2012). A modest increase in physical activity of only 1% in the Canadian population was estimated to have the potential to decrease health-care costs by 20.3 billion dollars over a 20 year period, generating savings of approximately 1 billion dollars per year (Krueger, Turner, Krueger, & Ready, 2013). Similarly, a 2012 estimate for the UK indicated that a modest increase in active travel could result in savings to the health-care system of approximately 17 billion £ over 20 years (Jarrett et al., 2012).

2.2 Correlates of active transportation

2.2.1 Socio-demographic correlates of active transportation

Consistent findings have emerged with regards to the association between socio-demographic characteristics and AT. AT is consistently shown to decrease with age (Adams, 2010; Ross, 2000; Tilt, Unfried, & Roca, 2007; Turrell et al., 2014; Van Dyck et al., 2010; Van Lenthe et al., 2005). This can been explained by an increase in responsibilities during adulthood that may decrease motivation for taking AT, and further decreases in older adulthood due to the reduction in mobility associated with old age (Adams, 2010). With respect to gender, some researchers find that males are more likely to engage in AT (Van Lenthe et al., 2005), although most find no significant difference (Adams, 2010; Owen et al., 2007; Ross, 2000; Tilt et al., 2007). Access to a car is inversely associated with AT (Adams, 2010; Giles-Corti & Donovan, 2002b; Turrell et al., 2013). Most research finds that those of low socio-economic status are more likely to engage in AT (Adams, 2010; Giles-Corti & Donovan, 2002b; Goodman, 2013; Miles et al., 2008; Owen et al., 2007; Pliakas et al., 2014; Turrell et al., 2013; Turrell et al., 2014; Van Dyck et al., 2010; Van Lenthe et al., 2005), while a few find the opposite (Ball et al., 2007; Cerin, Leslie, & Owen, 2009; Zander, Rissel, Rogers, & Bauman, 2015) or no significant differences (Cora L. Craig, Brownson, Cragg, & Dunn, 2002; Owen et al., 2007).

2.2.2 Distance as a correlate of active transportation

Distance to the destination of travel is one of the most significant factors explaining transport mode choice (Schlossberg, Greene, Phillips, Johnson, & Parker, 2006) and it is consistently negatively associated with AT (H. M. Badland, Schofield, & Garrett, 2008; H. M.

Badland, Schofield, & Schluter, 2007; Shannon et al., 2006). Research has demonstrated that the prevalence of actual-use of AT to work and perceiving that one is able to access the workplace by active modes of transportation both decline as distance increases (H. M. Badland et al., 2007).

2.4 The built environment determinants of active transportation

2.4.1 Mechanism linking the built environment to active transportation

An extensive body of literature has examined the environmental determinants of AT (B. Saelens et al., 2003; Sallis et al., 2004; Sugiyama et al., 2012). According to an extension of the discrete choice model of travel behavior, the built environment can affect AT mode choice by influencing aspects of the travel experience for a given mode, such as the time, cost, and comfort of travel. The discrete choice model of travel behavior contends that individuals will choose a particular travel mode according to the utility of that mode compared to all other modes. In other words, the individual will weigh the advantages and disadvantages of the set of travel modes available to him and choose the mode that is the most advantageous (S. Handy, Cao, & Mokhtarian, 2005; S. L. Handy, 1996).

2.4.2 Walkable built environments

A bulk of research has concentrated on determining the environmental features that characterize walkable built environments (B. Saelens et al., 2003; Van Dyck, Deforche, Cardon, & De Bourdeaudhuij, 2009). Researchers have examined numerous environmental features such as presence and quality of infrastructure for AT (sidewalks, bicycle paths) (Kaczynski & Henderson, 2008; Timperio, Crawford, Telford, & Salmon, 2004), access to public transit (Besser & Dannenberg, 2005; Wasfi, Ross, & El-Geneidy, 2013), aesthetics

(Cohen et al., 2014; Francis, 2010) and parks (Kaczynski & Henderson, 2008; McCormack, Rock, Toohey, & Hignell, 2010; Timperio et al., 2004). Amongst the multitude of features examined connectivity, access to destinations, and land-use mix have all been consistently positively related to AT (Ball, Bauman, Leslie, & Owen, 2001; Cerin, Leslie, du Toit, Owen, & Frank, 2007; Cleland, Timperio, & Crawford, 2008; Cora L. Craig et al., 2002; Forsyth, Hearst, Oakes, & Schmitz, 2008; Grow et al., 2008; Hoehner, Ramirez, Elliott, Handy, & Brownson, 2005; C. Lee & Moudon, 2006; Nelson & Woods, 2010; B. Saelens et al., 2003; Sallis et al., 2006; Sallis et al., 2004; Sugiyama et al., 2012).

2.4.3 Connectivity

Connectivity is a measure of the ease at which an individual can move from one destination to the next using the road network. Low connectivity is characteristic of many suburbs where there are few route choices due to barriers such as highways, few intersections, and large blocks. Highly connective areas will have few barriers, which will facilitate active travel by making it easy for travellers to access multiple destinations in little time (B. Saelens et al., 2003). Connectivity can be measured subjectively using surveys and can also be measured objectively via GIS using a number of indicators such as block length, block size, intersection density, percent four-way intersections, street density, connected intersection ratio, link node ratio (Berrigan, Pickle, & Dill, 2010) and number of dead end roads.

Accumulating evidence from cross-sectional studies (Deforche, Van Dyck, Verloigne, & De Bourdeaudhuij, 2010; Grow et al., 2008; Nelson & Woods, 2010; Trapp et al., 2012; Witten et al., 2012), longitudinal studies (Cleland et al., 2008) and systematic reviews (B. Saelens et al., 2003; Sugiyama et al., 2012) suggests that street connectivity is positively associated with AT. For example, a prospective study demonstrated that baseline perceptions of neighborhood connectivity were predictive of increases in transport related walking over a two-year period (Cleland et al., 2008). In another study, neighborhood connectivity was positively associated with AT after accounting for neighborhood self-selection (Witten et al., 2012). Implying that connectivity may incite individuals to take active transportation, even amongst those that do not have a preference for walkable built environments.

2.4.4 Access to destinations

Access to destinations is another aspect of the built environment that is thought to encourage individuals to take active means of transport. Measures of access to destinations aim to quantify the concentration or number of non-residential destinations that an individual has access to within an area. In areas with high accessibility, the presence of shorter travel distances to destinations will make AT a more feasible travel option (S. L. Handy, 1996). Measures of access to destinations are measured using objective measures such as audits, counts of destinations derived from GIS, (Hoehner et al., 2005) and kernel densities (Kestens, Lebel, Daniel, Thériault, & Pampalon, 2010) or alternatively by subjective measures derived from surveys (Hoehner et al., 2005).

Many studies have demonstrated that access to destinations is positively associated with AT (Ball et al., 2001; Cerin et al., 2007; Cora L. Craig et al., 2002; Forsyth et al., 2008; Giles-Corti & Donovan, 2002b; Hoehner et al., 2005; King et al., 2003; C. Lee & Moudon, 2006; B. E. Saelens & Handy, 2008; Tilt et al., 2007). In a review of the literature on destination and route attributes that incite walking for transport in adults, the presence and proximity of retail and service destination was associated with walking for transport in 80% of the studies reviewed. In a cross-sectional study examining physical activity behaviour, using both subjective and objective measures of access to destinations, it was revealed that having a high number of non-residential destinations within walking distance of the home increased the likelihood that participants would meet physical activity recommendations by means of AT (Hoehner et al., 2005). Findings from another study indicated that a measure of overall proximity to destinations was positively associated with active travel. Significant positive relationships were also observed for proximity to specific types of destinations such as food stores, retail stores, schools, post offices, restaurants/cafés, recreational facilities, parks, and the workplace, with monthly walking to these types of destinations (Cerin et al., 2007).

2.4.5 Land-use mix

Land-use mix is another destination-based measure of environmental exposure that is consistently positively associated with AT (B. Saelens et al., 2003). This measure gives an indication of the diversity of land-uses or destination types that an individual has access to within an area (Duncan et al., 2010). Areas with a high land-use mix are characterized by having multiple types of land-uses within their boundaries such as residential, commercial, recreational, and institutional (B. Saelens et al., 2003). This diversity of destination types is thought to incite individuals to choose active travel modes (Duncan et al., 2010), since when land-use mix is high distances between different types of non-residential destinations are shorter. Summary scores of the diversity of destination types are often used to compute land-use mix these include: dissimilarity scores, gravity indexes, and absolute clustering scores (B. B. Brown et al., 2009). One of the most frequently used indicators of land-use mix is the entropy index, whereby a score approaching 1 signifies heterogeneity and a score approaching 0 homogeneity of land-uses within a given area (B. B. Brown et al., 2009).

Numerous studies have found positive correlations between land-use mix and active transportation (Christian et al., 2011; Duncan et al., 2010; Gehrke & Clifton, 2014; B. Saelens et al., 2003; B. E. Saelens & Handy, 2008; Sallis et al., 2004; Srinivasan, 2002). In a meta-review of 13 reviews published between 2002 and 2006, mixed land-use was identified as an important correlate of walking. In a subsequent review of the literature of studies published between 2005 and 2006, the researchers observed that 8 out of eleven studies exhibited positive relationships between walking for transportation and land-use mix (B. E. Saelens & Handy, 2008). In another study examining variations in the entropy index and their relation to AT, land-use mix was consistently positively associated with AT to work using a two-category mix, three-category mix, and six-category mix (B. B. Brown et al., 2009).

2.5 Self-selection bias

The research studying the relationship between the built environment and AT has mainly been of a cross-sectional nature, which makes it especially vulnerable to self-selection bias (Boone-Heinonen, Guilkey, Evenson, & Gordon-Larsen, 2010). Differences in travel patterns between areas of low and high walkability may not arise due to the built environment alone but instead may partly reflect individuals travel preferences. Individuals may choose a residential location to facilitate taking specific travel modes, and thus the amplitude of relationships between the built environments and AT may be overestimated if behavioural preferences are not accounted for (Zhou & Kockelman, 2008). Many researchers have addressed this issue by controlling for the attitudes of travellers towards travel modes or neighbourhood characteristics (Sallis et al., 2009; Zhou & Kockelman, 2008). Despite widespread recognition of the issue of self-selection bias, it still remains a persistent issue in studies on travel behaviour, as addressing it often requires specific designs or questions on travel attitudes that are not yet regularly available in typical household travel surveys (Zhou & Kockelman, 2008).

2.6 Socioeconomic status, the built environment, and active transportation

There is a limited evidence base confirming the notion that walkable built environments equally influence the active transport decisions of those from different SES neighbourhoods. Of the research conducted to date the results are inconsistent.

Studies conducted in samples of children indicate that those of different socio-economic groups do not benefit equally from walkable built environments. Results from an analysis on children between the ages of 4 and 18 (N=323) demonstrated that high walkability had a stronger effect on the active transportation of children from high-income neighborhoods (Kerr et al., 2006). Similarly, findings from a study conducted using a household travel survey of 3,161 children from Atlanta also suggests that children from low-income groups are less responsive towards the built environment (Kerr, Frank, Sallis, & Chapman, 2007).

In contrast, research conducted with adult samples has obtained equivocal findings. Results from a study, conducted in Adelaide Australia using a sample of 2650 adults, indicated that proximity to commercial destinations had a greater association with monthly walking for transport for individuals of high socio-economic status than for individuals of low socio-economic status (Cerin et al., 2007). Using a sample of 2,199 adults from two regions in the United-States, researchers observed that the built environment was not associated with walking for transport for residents from low socio-economic status neighborhoods, whereas there was a significant positive association between walkability and frequency of walking for transport for residents from high socio-economic status neighborhoods. However, after controlling for neighborhood self-selection the interaction became non-significant (Sallis et al., 2009). These results are congruent with a Belgian study conducted with a sample of 1,200 adults and an Australian study conducted with a sample of 2,650 adult participants, that observed no significant interactions between walkability and neighborhood socio-economic status (Owen et al., 2007; Van Dyck et al., 2010).

2.7 Measuring environmental exposure

2.7.2 Fixed definitions of context

How to best measure exposure to the environment has long been a subject of fierce academic debate in contextual effects research. Most researchers have resorted to using a fixed definition of context, whereby they focus on a single exposure area that is deemed to be central and therefore assumed to be the most meaningful for measuring people-environment exposure (Perchoux, Chaix, Cummins, & Kestens, 2013). It is unsurprising given that individuals spend the majority of their time within their home environments and its centrality to daily mobility, that most researchers choose to focalize their assessment of environmental exposure on the residential neighborhood. Evidently, this choice is also guided by availability of spatial information, for in contrast to other locations in which individuals may spend their time, residential information such as residential postal codes is routinely collected (Perchoux et al., 2013) and thus is comparatively more likely to be available and accessible for analyses. These postal codes can then be used to obtain precise geographical coordinates that will permit the computation of the residential neighborhood using fixed or ego-centered neighborhood boundaries (Chaix, 2009).

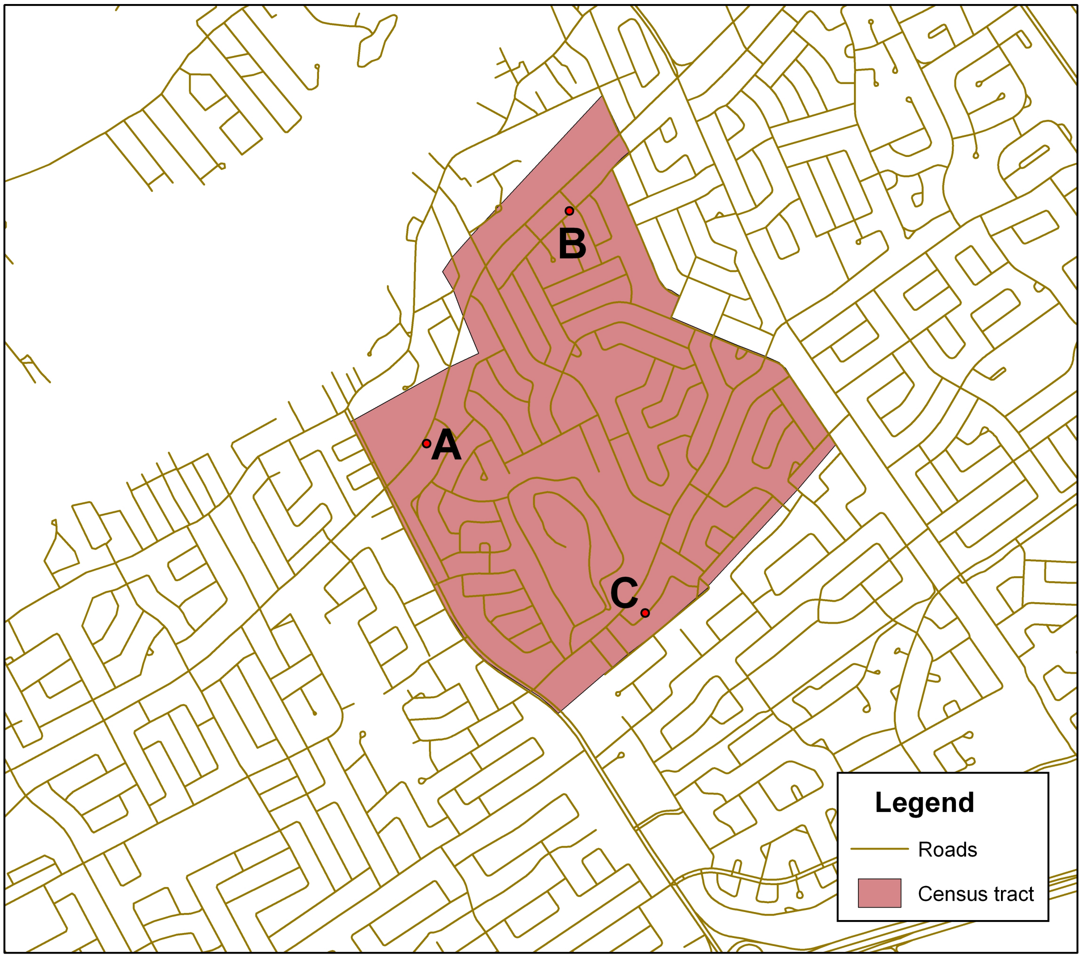

Figure 1: Census tract encompassing three residences A, B, and C. Administrative unit (in this case census tract) derived measures of exposure are measured using the boundaries of the unit. Participants from residences A, B, and C would be attributed the same environmental exposure, despite their different locations within the unit.

A fixed spatial delimitation of a neighborhood will consist of using pre-defined spatial units that encompass the location of interest to define the neighborhood such as census tracts, census block groups, voting precincts, and other administrative units (Oliver, Schuurman, & Hall, 2007). Such definitions of context have been argued to give an inaccurate representation of neighborhood exposure, due to their uniform attribution of exposure to all individuals residing within the unit regardless of their true spatial location (figure 1) (Perchoux et al., 2013).

In response to this criticism, many researchers have shifted towards the use of ego-centered definitions of place using the spatial location of the individual's residence as their focal point. The circular and road-network buffer are often used to define an ego-centered area. Circular buffers are nucleated around a specific location (such as the residence) and are defined by a given distance threshold. This distance is variable and is designated by the researcher in order to produce an area of an appropriate spatial scale for the study of the phenomenon of interest. However, there is a disadvantage associated with the use of circular buffers for the computation of environmental exposure, when examining the environmental determinants of active transportation. Circular buffers will encompass areas that are inaccessible by active means of transport due to physical barriers such as lakes, cliffs, railways or highways (Oliver et al., 2007).

The polygon based road-network buffer will avoid this shortcoming by only encompassing an area that falls within a set radius from the center that can be accessed via the street network. For example, the vertices of a 400-meter street network buffer around an individual's location of residence are obtained using all points that are 400 meters away from the location of residence using the street network (figure 2). These vertices are then joined using straight lines to form an irregular polygon (Oliver et al., 2007).

Researchers that have used fixed or ego-centered neighborhood boundaries centered on the place of residence to define exposure areas fall into what many critics describe as the "local trap" (Perchoux et al., 2013). The local trap emphasizes that the local scale is not always the most meaningful or representative unit of analysis to be used for the examination

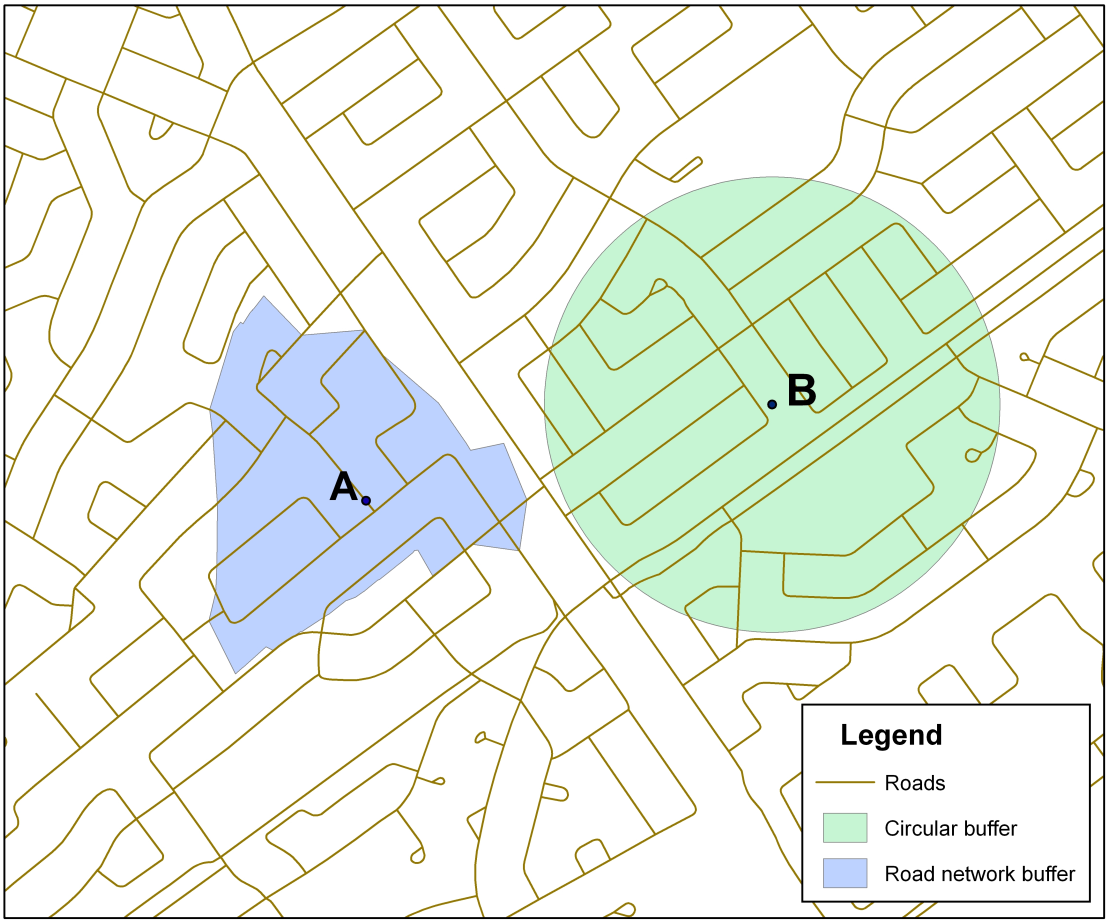

Figure 2: A 400 meter road-network buffer and a 400 meter circular buffer. A gives the approximate spatial location of the residence that was used to compute the road-network buffer and B the location of the residence used to compute the circular buffer.

of the effect of context on health (Cummins, 2007). Studies that have limited their analyses to the local scale have been innovative in the public health and transport fields, however they have neglected to take into account an important human trait, namely, that people are mobile (Kwan, 2009). Limiting our unit of analysis to the residential neighborhood may be justifiable for people with reduced mobility such as the elderly, young children, and some spatially segregated groups such as certain ethnic minorities, however most individuals are mobile, accessing many destinations and their heterogeneous environmental features that lie outside the residential neighborhood (Perchoux et al., 2013).

2.7.3 Dynamic definitions of context

Given that individuals are mobile and built environment exposure differs from place to place, it is essential that we take into account the multiple places that individuals will access in time and space to avoid underestimating an individual's true environmental exposure (Cummins, 2007). Thus, many researchers have shifted from using fixed representations of context focused on the residential neighborhood to using dynamic definitions of context that take into account multiple exposure areas (Perchoux et al., 2013). Travel diaries, global

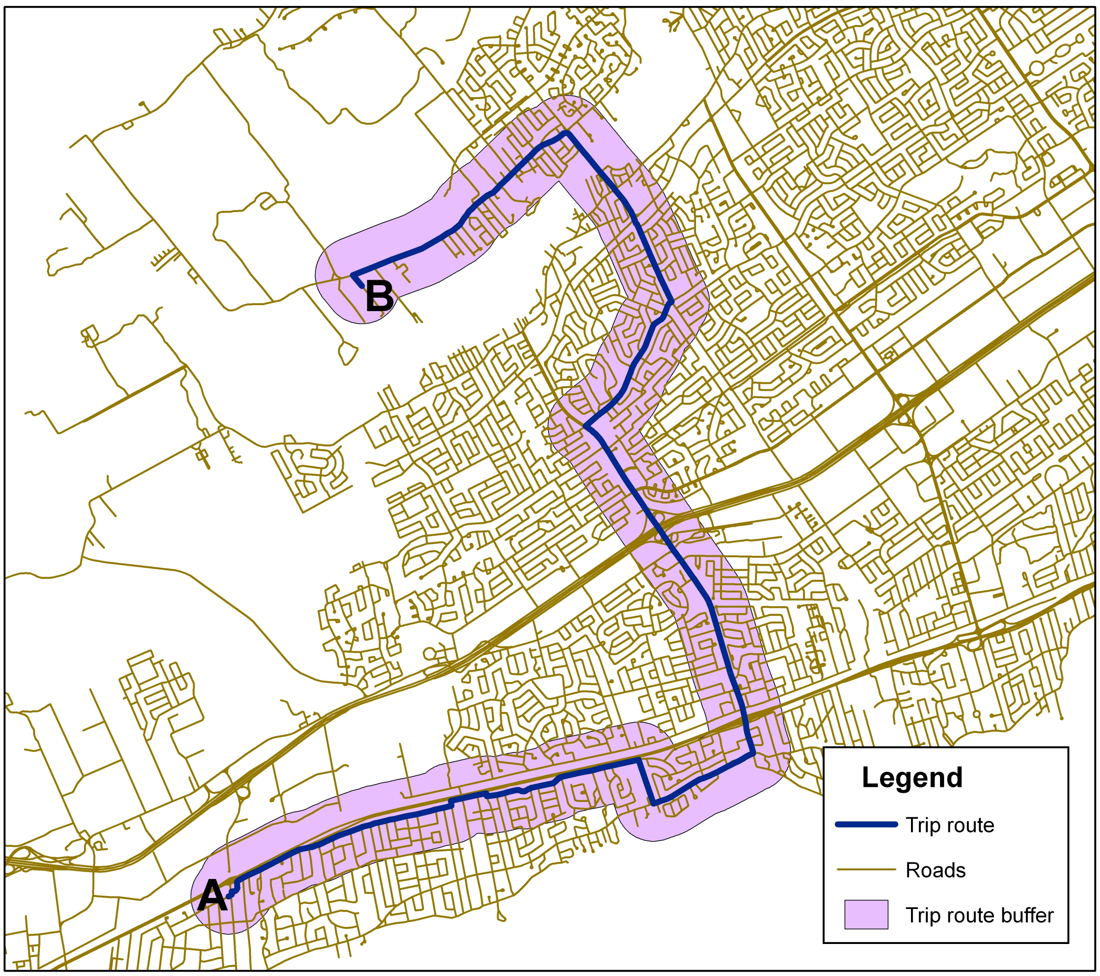

Figure 3: Buffer of a trip route. A gives the approximate spatial location of the trip origin A and B the approximate location of trip destination B.

positioning systems (GPS) and new tools such as web based interactive mapping questionnaires have allowed for the collection of detailed activity and locational information (Chaix et al., 2012). This has permitted environmental exposure to be assessed using methods such as deviational ellipses, convex envelopes (Perchoux et al., 2013) and buffers of the trip route (figure 3) (H. Badland & Schofield, 2005; van Heeswijck et al., 2015).

In the context of research conducted to examine the environmental determinants of active transportation, researchers have used buffers of trip routes to account for non-residential built environment exposure (H. M. Badland et al., 2008; van Heeswijck et al., 2015; Winters, Brauer, Setton, & Teschke, 2010). Amongst these studies, some have combined trip level measures to obtain measures of activity space environmental exposure, whereas others have conducted their analyses at the trip level (H. M. Badland et al., 2008; Winters et al., 2010). Trip level analyses may allow for a more accurate prediction of AT by potentially avoiding a loss in measurement precision that may occur during the aggregation of trip level measures. Incorporating this method of spatial analysis in studies examining the determinants of AT has the potential to improve our ability to identify it's environmental determinants and to refine our operationalization of environmental exposure.

Summary statement, rationale for research, and research question

Active transportation is increasingly on the policy agenda of decision makers (Goodman, 2013; Sallis et al., 2015) and environmental interventions are progressively being identified as plausible methods of inducing population wide increases in physical activity in disadvantaged communities (L. D. Frank et al., 2008). Thus, researchers have called for policymakers to modify the built environment determinants of active travel in low SES areas in the hopes of reducing disparities in physical activity and health (C. Lee & Moudon, 2006; Sallis et al., 2009; Sallis et al., 2011; Turrell et al., 2013; Van Dyck et al., 2010).

Research finding that the built environment interacts with neighbourhood socio-economic status advances the theory that residents from high SES neighbourhoods may reap the benefits of supportive environment, whilst those from low SES neighbourhoods accrue no advantages (Cerin et al., 2007; Kerr et al., 2007; Kerr et al., 2006). Yet, several other studies contradict this theory (Owen et al., 2007; Sallis et al., 2009; Van Dyck et al., 2010).

The ambivalence of these findings in the literature could be arising as a consequence of measurement error. Analogous to other research on contextual effects, studies that have examined whether the influence of the built environment on active transportation differs for different socio-economic groups have ignored non-residential locations in their measures of the built environment, even when examining AT that may occur outside of the residential neighborhood. Exposures from within the entirety of an individual's spatial trajectory from a given origin to a destination have the potential to motivate behavior. Thus, the practice of limiting our measurements of exposures to the residential neighborhood when examining environment-individual interactions could result in the neglect of many exposures that could act as key drivers of active transportation mode choice.

Consistent analytical evidence is of the essence to assure that the information guiding future interventions are sound. Given the equivocal nature of the evidence to date and its susceptibility to measurement error, further research is needed to determine if changing the built environment could help reduce disparities in physical activity. Few studies have used measures of the built environment of the travel route to examine the relationship between built environment features and AT (H. M. Badland et al., 2008; van Heeswijck et al., 2015; Winters et al., 2010) and even fewer have conducted their analyses at the trip level (H. M. Badland et al., 2008; Winters et al., 2010). Trip level analyses may allow for a more accurate prediction of AT. Yet, to our knowledge, no studies have conducted a trip level analyses when examining interactions between SES and the built environment. Our study will make a significant contribution to the literature by conducting a trip level analyses, whereby we calculate measurements of exposure to the built environment for the estimated trip routes taken by individuals during their daily activities.

This thesis aims to answer the specific question:

- Does socio-economic status modify the effect of built environment characteristics, connectivity, land-use mix, and access to destinations, on active transportation?

Article: Does the effect of walkable built environments vary by neighbourhood socioeconomic status?

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Abstract

Objective. To examine socioeconomic status as a moderator of the relationship between the built environment and active transportation such as walking or cycling using measures of built environment exposure derived from individuals transport trips.

Methods. The 2008 Montreal Origin-Destination (OD) survey provided origin destination coordinates for a sample of 156,700 participants. We selected participants from this survey that had travelled within the census metropolitan area of Montreal the day preceding the interview, and that were between 18-65 years of age. Measures of connectivity, land-use mix, and density of business and services were collected using 400-meter buffers of the trip routes. Logistic regression was used to model the relationship between built environment variables and active transportation..

Results. Trip routes in the 2nd, 3rd and 4th quartile of density of business and services or connectivity translated into greater odds of taking AT (compared to a trip in the lowest quartile). Trip routes in the 2nd, 3rd , and 4th quartile of land-use mix translated into lower odds of taking AT. Trips in the highest quartiles of connectivity and density of business and services were found to have a weaker association with active transportation if the individual undergoing the trip was from a low SES neighbourhood.

Conclusion. Our results suggest that previous studies finding no effect modification may have been due to the limitation of measurements of exposures to the residential neighbourhood.

Key words: Active transportation; Physical activity; Walkability; Neighborhood socioeconomic status; Connectivity; Land-use mix; Density of destinations

Introduction

Studies examining disparities in physical activity find that those of low socioeconomic status (SES) engage in insufficient recreational physical exercise to meet recommended physical activity guidelines (Giles-Corti & Donovan, 2002). Given the health benefits of active transportation (AT) (Hamer & Chida, 2008; Pucher, Buehler, Bassett, & Dannenberg, 2010), and its higher prevalence amongst those of low SES (Adams, 2010; Giles-Corti & Donovan, 2002; Goodman, 2013; Miles, Panton, Jang, & Haymes, 2008; Owen et al., 2007; Pliakas, Wilkinson, & Tonne, 2014; Turrell, Haynes, Wilson, & Giles-Corti, 2013; Turrell, Hewitt, Haynes, Nathan, & Giles-Corti, 2014; Van Dyck et al., 2010; Van Lenthe, Brug, & Mackenbach, 2005), implementing health promotion efforts to induce further increases in AT in disadvantaged areas may be an effective way of diminishing health disparities (Sallis et al., 2011; Turrell et al., 2013; Van Dyck et al., 2010) and in inducing widespread population level increases in physical activity (De Nazelle et al., 2011; Ogilvie, Egan, Hamilton, & Petticrew, 2004).

A vast body of literature has focused on examining the association between aspects of the built environment and mode choice (Broberg & Sarjala, 2015; Cervero, 2002; Cervero & Kockelman, 1997; Dalton, Jones, Panter, & Ogilvie, 2013; Ding, Lin, & Liu, 2014; Ewing & Cervero, 2001; Ewing et al., 2015; Guo, Bhat, & Copperman, 2007). The literature studying the relationship between physical activity and the physical environment have found that 3 key elements of the physical environment of the neighborhood, greater proximity to retail destinations (Ball, Bauman, Leslie, & Owen, 2001; Cerin, Leslie, du Toit, Owen, & Frank, 2007; Craig, Brownson, Cragg, & Dunn, 2002; Forsyth, Hearst, Oakes, & Schmitz, 2008; Hoehner, Ramirez, Elliott, Handy, & Brownson, 2005; King et al., 2003; Lee & Moudon, 2006; van Heeswijck et al., 2015), high connectivity (Cleland, Timperio, & Crawford, 2008; Deforche, Van Dyck, Verloigne, & De Bourdeaudhuij, 2010; Grow et al., 2008; Nelson & Woods, 2010; Saelens, Sallis, & Frank, 2003; Sugiyama, Neuhaus, Cole, Giles-Corti, & Owen, 2012; Trapp et al., 2012; Witten et al., 2012), and high land-use mix (Giles-Corti & Donovan, 2002; Saelens et al., 2003; Sallis, Frank, Saelens, & Kraft, 2004; Sugiyama et al., 2012) are related to walking and biking for transportation.

The modification of the physical environment to create walkable built environments in areas of low SES has been suggested as a method of increasing physical activity levels in low SES communities (Lee & Moudon, 2006; Sallis et al., 2009; Turrell et al., 2013; Van Dyck et al., 2010), subsequently reducing SES inequalities in physical activity. However, it is possible that not all socioeconomic groups benefit equally from walkable built environments (Sallis et al., 2009).

Studies that have examined whether the influence of the built environment on AT differs for different socioeconomic groups have obtained mixed results (Kerr, Frank, Sallis, & Chapman, 2007; Kerr et al., 2006; Owen et al., 2007; Sallis et al., 2009; Van Dyck et al., 2010). The equivocal nature of these findings could be due to the way measures of the built environment were determined. More specifically, most studies have examined the built environment in residential settings ignoring non-residential destinations. Limiting the analysis to the residential neighborhood may be justifiable for people with reduced mobility such as the elderly, young children, and some spatially segregated groups such as certain ethnic minorities. However, most individuals are mobile and access destinations with heterogeneous environmental features that lie outside their residential neighborhood (Perchoux, Chaix, Cummins, & Kestens, 2013). Built environment features along the entirety of the spatial trajectory between origin and destination may have the potential to influence AT mode choice. Thus, the current practice of limiting our measurements of exposures to the residential neighborhood when examining environment-individual interactions can result in the neglect of many exposures that could act as key drivers of this behavior.

One method of taking into account the non-residential context when examining mobility is to use buffers of the trip route to measure environmental exposure(Badland, Schofield, & Garrett, 2008; Chaix et al., 2014; van Heeswijck et al., 2015; Winters, Brauer, Setton, & Teschke, 2010). Amongst the studies using this method some have conducted their analyses at the individual level by combining trip measures in order to obtain measures of activity space environmental exposure, whereas others have conducted their analyses at the trip level (Badland et al., 2008; Chaix et al., 2014; Winters et al., 2010). Trip level analyses may allow for a more accurate prediction of AT by potentially avoiding a loss in measurement precision that may occur during the aggregation of trip level measures.

Yet, to our knowledge, no studies have conducted a trip level analysis when examining interactions between SES and the built environment. In our research, we aim to examine whether individual SES modifies the relationship between built environment attributes and AT using a sample of 201,189 trips. We address previous methodological limitations by performing a trip level analysis using estimated travel routes between origin and destination pairs.

Methods

Study Sample

The sample was drawn from the 2008 Montreal Origin-Destination computer-assisted phone interview survey. This survey provides geographic coordinates for the origins and destinations of trips taken for a representative sample of participants above the age of four residing in the metropolitan region of Montreal. Respondents provided by phone individual information such as age, sex, possession of a driver's license, employment and travel information for themselves and for their household members for the day preceding the interview. For every trip, phone respondents were asked to report, travel mode, starting point (origin) and ending point (destination). The 2008 survey provided weekday travel information for a sample of 156,700 people undergoing 354915 trips. All trips made within the census metropolitan area of Montreal by participants aged between 18-65 years were retained for this study.

Measures

We integrated travel survey data with spatial information on roads, land-use, commercial destinations, and the census within the MEGAPHONE (Daniel & Kestens, 2007) GIS using ArcGIS 10.1. The shortest route between each origin-destination pair, that didn't include travel by highway or ferry, was computed using Network Analyst. We included only walkable segments (i.e elimination of highways) of the route network in our analysis, since we wanted to compute the walking or biking pathway for each origin-destination pair. We assumed that the shortest route between two origin-destination pairs has a high probability of being similar to a route that would be picked by an individual for AT. Each route served as a basis for the computation of a 400-meter buffer area that was used to calculate measures of density of business and services, connectivity and land-use mix. Even if the actual route may differ a bit from the shortest path, we hypothesized that participants wouldn't engage in too long of a detour, so that a 400-meter buffer along the shortest path would adequately represent the actual route.

Active Transport

The dependent variable active transport was created using the variable travel mode for each trip that was self-reported during the Origin-destination survey. The answers of respondents were categorized to form the binary dependent variable active (walking, biking) versus passive (all other) means of transport. For multimodal trips, the travel mode was only considered active if one of the reported modes was either walking or cycling.

Density of Business and Service Destinations

The businesses and services were obtained from the 2008 DMTI Enhanced Points of Interest database of Quebec, a provincial database containing 363,191 businesses and services. We excluded businesses and services that were industrial or utilities in our analysis, as they were not considered to be destination that will incite individuals to take active means of transportation. Kernel density estimations were computed for the final sample of destinations lying within the boundaries of the census metropolitan area of Montreal (n=191,688). We used quartic kernels with an adaptive bandwidth using 5% of the observations for the computation. The use of an adaptive bandwidth reflected our conceptualization of the influence that destinations would have on walking behaviors. We hypothesized that the spatial influence of a given business or service was inversely related to its proximity to similar destinations (Kestens, Lebel, Daniel, Theriault, & Pampalon, 2010). Destinations located in areas with few other businesses and services (low density areas) will have a greater catchment area than destinations in high-density locations, since they are likely to be associated with longer trips. This is because in dense areas competition prevents individuals from having to travel long distances (Kestens et al., 2010).

A measure of average density of business and service destinations was computed using the buffers of the trip routes. Densities were then categorized into quartiles due to their non-normal distribution.

Connectivity

We calculated connectivity using the DMTI 2010 road-network file by computing the density of 4 way or more intersections falling within the trip route buffer areas. Connectivity was also categorized into quartiles due to its non-normal distribution

Land-use mix

We used the DMTI 2007 land-use file to identify land-uses within our buffers. We used the following 5 land-use categories: commercial, government, open area, residential, and parks and recreational. We excluded land-uses that were not considered to be relevant in terms of inciting people to walk or bicycle (industrial land-uses, and resource based land-uses such as power plants and sewage treatment plants). The land-use mix measures were calculated using the following formula (entropy index) (Duncan et al., 2010; Frank, Andresen, & Schmid, 2004; Hajna, Dasgupta, Joseph, & Ross, 2014):

$$\mathrm{E}Z = -\sum_k \left(\frac{A_{kz} \ln A_{kz}}{\ln N}\right)$$

where E_Z is the entropy index of buffer zone Z, k is the category of land-use, A_{kz} is the percent of land use k in buffer zone Z, and N is the number of land-use categories. Our N was a constant value, since it represented the number of land-use categories considered within the study area rather than the number of land-uses present within each individual trip buffer (Hajna et al., 2014). The index values vary between 0 and 1 where 0 represents a single land-use, and 1 the most diversified set of land-uses. Land-use mix was categorized into quartiles.

Neighborhood Socioeconomic status

SES of the neighborhood was used as a proxy for individual SES and was calculated using the 2006 Pampalon index of material disadvantage (Pampalon et al., 2012) using a 400-meter road-network buffer centered on the residence of each participant. This index is created from a principal component analysis at the dissemination area level using the following census variables: the proportion of people without a high school diploma, personal average income, and the ratio of employed to the population. Assuming that the population is spread evenly across the dissemination areas, the average material deprivation around each home was computed using the following formula:

$$M_z = \frac{\sum_d M_d C_{zd} P_d}{\sum_d C_{zd} P_d}$$

where M_Z is the material deprivation index M of buffer zone Z, M_d is the material deprivation index of a dissemination area d, C_{zd} is the proportion of the area of Z taken up by d, P_d is the population of a dissemination area d. We then used the median of this variable to create a binary variable high versus low socio-economic status.

Covariates

Demographic covariates measured in the survey included: sex, age, possession of a driver's license (yes versus no), and employment status. Employment status was classified to form a binary variable (employed, yes versus no). Additionally, a shortest distance measure between origin and destination was computed for each trip using ArcGIS Network Analyst. We categorized distance into four groups, ≤1km, >1km and ≤5km, >5km and≤ 10km, >10km.

Analyses

Chi^2 tests were used to see if the built environment characteristics of the trip differed by neighborhood socio-economic status. Then using binary logistic regression in SPSS, the relationship between density of business and service destinations, connectivity, and land-use mix, along the estimated trip routes, and the probability of taking AT for that trip was examined. Models were adjusted for all demographic covariates and distance. Then another model was run where interaction terms were added for each built environment attribute and neighborhood SES. Finally, we stratified by SES and ran separate logistic regression models for the 2 samples.

Results

Out of 354,915 trips, 153,726 trips were excluded for they did not meet the inclusion criteria. Our final sample was comprised of 201,189 trips from 74,482 participants from 45,301 households.

Descriptive analyses

The average age of respondents was 42.17, with a higher number of women, respondents with a driver's license and respondents employed full-time (table 1). Those that engaged in active transport and those that engaged in passive transport differed in terms of their socio-demographic characteristics (table 2). 10.5% of trips were under 1km and 33.3% were under 5km in length (table 3). Chi^2 tests were significant for all environmental characteristics.

Logistic regression analyses

Age was negatively associated with AT. Being a man, not holding a driver's license, or being unemployed translated into greater odds of engaging in AT for a trip. Traveling more than 1km to get to a destination translated into lower odds of taking active means of transport for a trip. In terms of built environment variables, if a trip route was in the 2nd, 3rd or 4th quartile of density of business and services or connectivity this translated into greater odds of taking AT (compared to a trip in the lowest quartile). Contrastingly, if a trip route was in the 2nd, 3rd or 4th quartile of land-use mix this decreased the probability of taking AT (Table 4).

Interaction analyses

Significant interactions with neighborhood SES were found for all three of the environmental variables. Connectivity was associated with increased odd's of taking AT, but for trip routes in the 2nd and 4th quartile of connectivity, this effect was weaker if the individual undergoing the trip was from a low SES neighborhood. Density of business and services of a trip was associated with increased odds of taking active transportation, but for trip routes in the 3rd and 4th quartile, this effect was weaker if those undergoing the trip were from low SES neighborhoods (Table 3).

Logistic regression analyses in stratified samples (figure 1 and 2)

The 2nd (OR=1.23, CI: 1.13-1.34), 3rd (OR=1.83, CI: 1.64-2.04) and 4th quartile (OR= 3.29, CI: 2.92-3.7)) of density of business and services and the 2nd (OR=1.18, 1.08-1.29), 3rd (OR=1.29, CI: 1.15-1.44) and 4th quartile (OR=2.13, CI: 1.90-2.39) of connectivity were positively associated with AT, if the individual undergoing the trip was from a high SES neighborhood. The 2nd (OR=1.17, CI: 1.08-1.27), 3rd (OR=1.47, CI: 1.35-1.61) and 4th quartile (OR= 2.67, CI: 2.41-2.95) of density of business and services and the 3rd (OR=1.12, CI: 1.01-1.23) and 4th quartile (OR=1.59, CI: 1.43-1.76) of connectivity were also positively associated with AT if the individual undergoing the trip was from a low SES neighborhood.

Discussion

In our study, we used innovative methods of measuring built environment characteristics to examine the moderating effect of neighborhood SES on the association between features of the built environment and active transportation. Given that the entirety of an individual's spatial trajectory could play a pivotal role in influencing their transport choices, we used measures of the built environment derived from estimates of the spatial trajectory of participant's potential AT trips to predict odds of AT. Our results indicated that for the trips of people from low SES neighborhoods connectivity, and density of business and services had a weaker association with active transportation compared to those of high SES. This suggests that previous studies finding no effect modification may have been due to the limitation of measurements of exposures to the residential neighborhood.

Our findings are contrary to the findings from most studies conducted with samples of adults (Owen et al., 2007; Sallis et al., 2009; Van Dyck et al., 2010). In the Belgian Environmental Physical Activity Study (BEPAS), a study conducted on 1200 adults aged 20-65, neighborhood SES did not modify the relationship between walkability and AT (Van Dyck et al., 2010). Their results are congruent with the neighborhood quality of life study (NQLS) and the Physical Activity in Localities and Community Environments (PLACE) study (Owen et al., 2007; Sallis et al., 2009). Contrastingly, Cerin et al. 2007 found that proximity to commercial destinations had a greater effect on monthly walking for transport for those of high SES than for those of low SES.

Our findings suggest that even when the right environmental conditions are present there may be other factors that will lessen the influence of favorable built environments on the AT behavior of those from low SES neighborhoods. Social characteristics of those from low-income neighborhoods such as a greater cultural acceptance of walking for transport, personal reasons such as the psychological stress (Delahanty, Conroy, Nathan, & Diabetes Prevention Program Research, 2006; Ng & Jeffery, 2003) from living in stressful conditions, lack of time (R. E. Lee & Cubbin, 2009) and characteristics of their surroundings such as increased exposure to criminality (Ross, 2000) or traffic (Sallis et al., 2011; Yiannakoulias & Scott, 2013) may be of greater consequence for their AT behavior than built environment characteristics.

It has been suggested that those of low SES groups are disproportionately exposed to area-level deprivation within both the residential and non-residential contexts (Shareck, Kestens, & Frohlich, 2014) contributing to the social isolation of the poor in disadvantaged places (Krivo et al., 2013). Even when built environment characteristics are favorable in low SES areas other features of the physical environment may be inequitably distributed (Cutts, Darby, Boone, & Brewis, 2009; Sallis et al., 2011), which may prevent low SES individuals from taking advantage of AT enhancing environment such as a lack of infrastructure including: adequate lighting, bike lanes, bike paths, and bicycle friendly parking (Craig, Cameron, Russell, & Beaulieu, 2001). Furthermore, disparities in the quality of neighborhood resources for AT (Cora Lynn Craig et al., 2001; Sallis et al., 2011; Zhu & Lee, 2008) and poorer neighborhood aesthetics (Lovasi, Hutson, Guerra, & Neckerman, 2009; Sallis et al., 2011; Zhu & Lee, 2008) could also contribute.

Overall, our findings suggest that the built environment has a weaker association with the active transportation of those from low SES neighborhoods. However, in terms of physical activity accumulated, the overall higher odds of taking active transport for those of low SES neighborhoods could compensate for the possible diminished influence of the built environment on active transportation. Furthermore, the active transport behavior of those from low SES neighborhoods was still positively associated with density of destinations and connectivity. Thus, modifying the built environment in areas of low SES could still result in increases in active transportation for those of low SES areas and has the potential to lead to reductions in SES inequalities in physical activity.

Limitations

We used cross-sectional data; therefore we cannot infer causality from our results. Individuals with a personal preference for walking and biking might choose to live and frequent activity-friendly environments to facilitate their travelling behavior, whereas those that dislike AT may have a personal preference for environments that undermine active travel (Cora L. Craig et al., 2002; Witten et al., 2012).

The built environment may affect physical activity using multiple complex mechanisms existing between physical activity and multiple aspects of regional settings, individual characteristics and group characteristics (Alfonzo, 2005). We only included three of the many built environment characteristics that may influence propensity to take AT, others include: presence and quality of infrastructure for AT (sidewalks, bicycle paths), cost of parking, and access to public transit. We did not include many regional characteristics of the setting such as climate and weather, individual level characteristics such as health status, race/ethnicity and attitudes towards AT, and group level characteristics such as culture in our analysis.

Our findings indicated that there was a higher probability of taking active transportation if a trip was in the lowest quartile of land-use mix. These findings could be due the dependency of the entropy index on the size of the units, whereby larger units may be attributed high land-use mix scores due to their greater size, and therefore have a greater probability of containing many land-uses within their boundaries (Duncan et al., 2010). Due to the variable size of trip buffers, future studies may want to correct for unit size in their measures of land-use mix.

There could be error associated with the use of neighbourhood SES as an indicator of personal SES, rather than using indicators of personal SES such as education or income. There may also be error associated with the fact that some of the GIS data used to calculate the environmental variables was from a different year than the OD survey.

A final limitation of our study is that measurement error may have occurred when respondents reported trips that were not his or her own. For example, previous findings indicate that in Montreal approximately 11% of commuters achieve their 30 minutes of recommended physical activity per day by walking to public transit stops (Wasfi, Ross, & El-Geneidy, 2013). However, in our sample respondents reported a very low percentage of multi-modal trips comprised of both an active transport and a public transport component, which suggests that these types of trips may have been under reported.

Conclusion

To conclude, this study contributed to the literature by examining if neighborhood SES modifies the relationship between the built environment and AT using measures of the built environment that take into account non-residential locations. Previous findings, indicating no significant interactions between the built environment and SES may have been due to the exclusion of non-residential settings. We urge future studies to use trips measures of the built environment.

Modifying the built environment in areas of low SES has the potential to lead to reductions in SES inequalities in physical activity. However, implementing built environment developments may not be enough to sufficiently promote active transportation. Interventions need to take into account individual and social environment factors that could act as considerable barriers to the success of interventions.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Table 1: Socio-demographic statistics for all sample participants.

Variable	Average (SD) or %
Complete Sample	
Age	42.17 (13.05)
Sex	
Man	47.7
Woman	52.3
License	
Yes	87
No	13
Employment Status	
Full-time	65.9
Part-time	6.5
At home	5.5
Other	2.6
Retired	8.6
Student	10.8

Location of the survey: Montreal, Quebec
Date of the survey: 2008
Data analysis: 2014
Study population: 74,482 adults (18-65)

Table 2: Socio-demographic statistics for participants that engaged in active transport and participants that engaged in passive transport.

Engaged in active transport	**Average (SD) or %**
Age	42.04 (13.55)
Sex	
Man	44.34
Woman	55.66
License	
Yes	69.22
No	30.56
Employment Status	
Full-time	50.75
Part-time	9.13
At home	11.65
Other	12.26
Retired	10.64
Student	5.60
Engaged in passive transport	**Average (SD) or %**
Age	42.19 (13.00)
Sex	
Man	48.04
Woman	51.96
License	
Yes	88.74
No	11.20
Employment Status	
Full-time	67.40
Part-time	6.27
At home	10.76
Other	8.21
Retired	5.01
Student	2.34

Location of the survey: Montreal, Quebec
Date of the survey: 2008
Data analysis: 2014
Study population: 74,482 adults (18-65)

Table 3: Modal and distance trip statistics.

Characteristic	Average (SD) or %
Distance	
0-1km	10.5
>1-5km	33.3
>5km and≤ 10km	21.4
>10km	34.8
Trip modes	
Single mode trips	
Only active transport	10.58
Public transport only	16.87
[a]Private vehicle only	70.30
Multi-modal trips	
Active transport and public transport	0.04
[a]Active transport and private vehicle	0.01
Public transport and private vehicle	2.13
Environmental characteristics	
Land-use mix	0.58(0.0003)
Connectivity (nb/km^2)	23.38(0.03)
Density of business and services (nb/km^2)	281.75(0.90)

[a]Private vehicles includes private automobile, taxi and motorcycle
Location of the survey: Montreal, Quebec
Date of the survey: 2008
Data analysis: 2014
Study population: 74,482 adults (18-65)

Table 4: Logistic regression model for predictors of taking active transportation without interaction terms.

	OR	95% C.I.
Sex (ref. man)		
Woman	0.872	0.841-0.905
Age	0.994	0.992- 0.995
Occupation (ref. employed)		
Unemployed	1.266	1.207-1.328
Distance (ref. 0-1km)		
>1≤ 5km	0.120	0.115-0.125
>5≤ 10km	0.015	0.014-0.016
> 10km	0.004	0.003-0.004
Drivers license (ref. yes)		
No	2.740	2.618-2.869
Density of business and services (ref. 1st quartile)		
2nd quartile	1.191	1.121-1.264
3rd quartile	1.595	1.491-1.706
4th quartile	2.935	2.720-3.167
Land-use mix (ref. 1st quartile)		
2nd quartile	0.882	0.839-0.926
3rd quartile	0.885	0.838-0.934
4th quartile	0.817	0.772-0.864
Connectivity (ref. 1st quartile)		
2nd quartile	1.137	1.064-1.214
3rd quartile	1.275	1.186-1.371
4th quartile	1.918	1.780-2.067
Neighborhood SES (ref. high)		
Low	0.891	0.859-0.925

SES, socioeconomic status
Location of the survey: Montreal, Quebec
Date of the survey: 2008
Data analysis: 2014
Study population: 74,482 adults (18-65)

Table 5: logistic regression model for predictors of taking active forms of transport with interaction terms.

Explanatory variables	**OR**	95% CI
Sex (ref. man)		
Woman	0.872	0.840-0.940
Age	0.993	0.992-0.995
Occupation (ref. employed)		
Not employed	1.269	1.210-1.331
Distance (ref. 0-1km)		
>1≤ 5km	0.120	0.116-0.125
>5≤ 10km	0.015	0.014-0.016
> 10km	0.004	0.003-0.004
Drivers license (ref. yes)		
No	2.753	2.629-2.882
Neighborhood SES (ref. high)		
Low	1.199	1.081-1.330
Density of destinations (ref. 1st quartile)		
2nd quartile	1.231	1.126-1.345
3rd quartile	1.845	1.652-2.062
4th quartile	3.374	2.993-3.805
Land-use mix (ref. 1st quartile)		
2nd quartile	0.842	0.783-0.907
3rd quartile	0.876	0.809-0.949
4th quartile	0.803	0.740-0.871
Connectivity (ref. 1st quartile)		
2nd quartile	1.169	1.067-1.280
3rd quartile	1.267	1.132-1.418
4th quartile	2.084	1.856-2.341
Density of destinations (ref. 1st quartile)***SES** (ref. high SES)		
2nd quartile* low SES	0.950	0.842-1.072
3rd quartile* low SES	0.795	0.691-0.914
4th quartile* low SES	0.769	0.659-0.898
Land-use mix (ref. 1st quartile)***SES** (ref. high SES)		
2nd quartile* low SES	1.085	0.984-1.196
3rd quartile* low SES	1.020	0.917-1.135
4th quartile* low SES	1.018	0.911-1.138
Connectivity (ref. 1st quartile)***SES** (ref. high SES)		
2nd quartile* low SES	0.862	0.755-0.985
3rd quartile* low SES	0.890	0.765-1.035
4th quartile* low SES	0.774	0.664-0.903

SES, socioeconomic status
Location of the survey: Montreal, Quebec
Date of the survey: 2008
Data analysis: 2014
Study population: 74,482 adults (18-65)

Figure 1: Odd's ratios of the built environment variables for trips where the individual undergoing the trip was from a high SES neighbourhood- in a SES stratified sample.

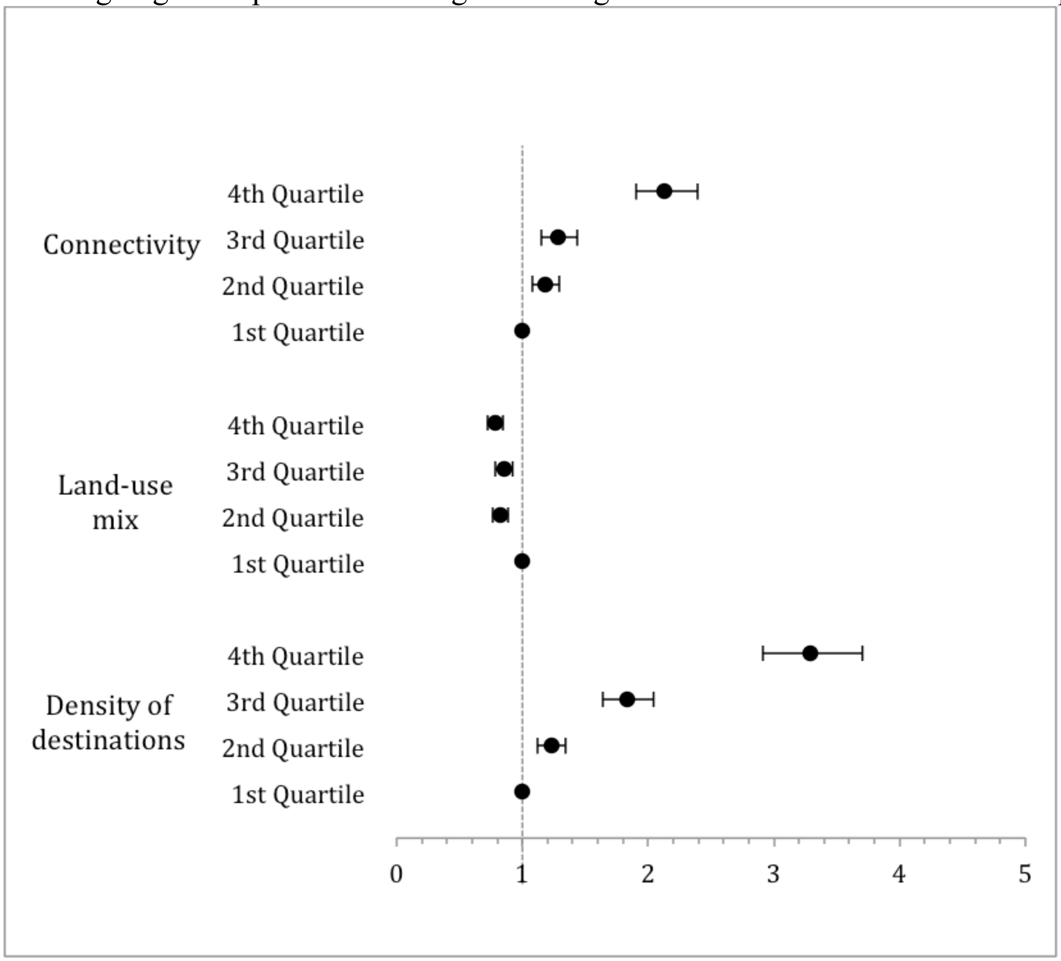
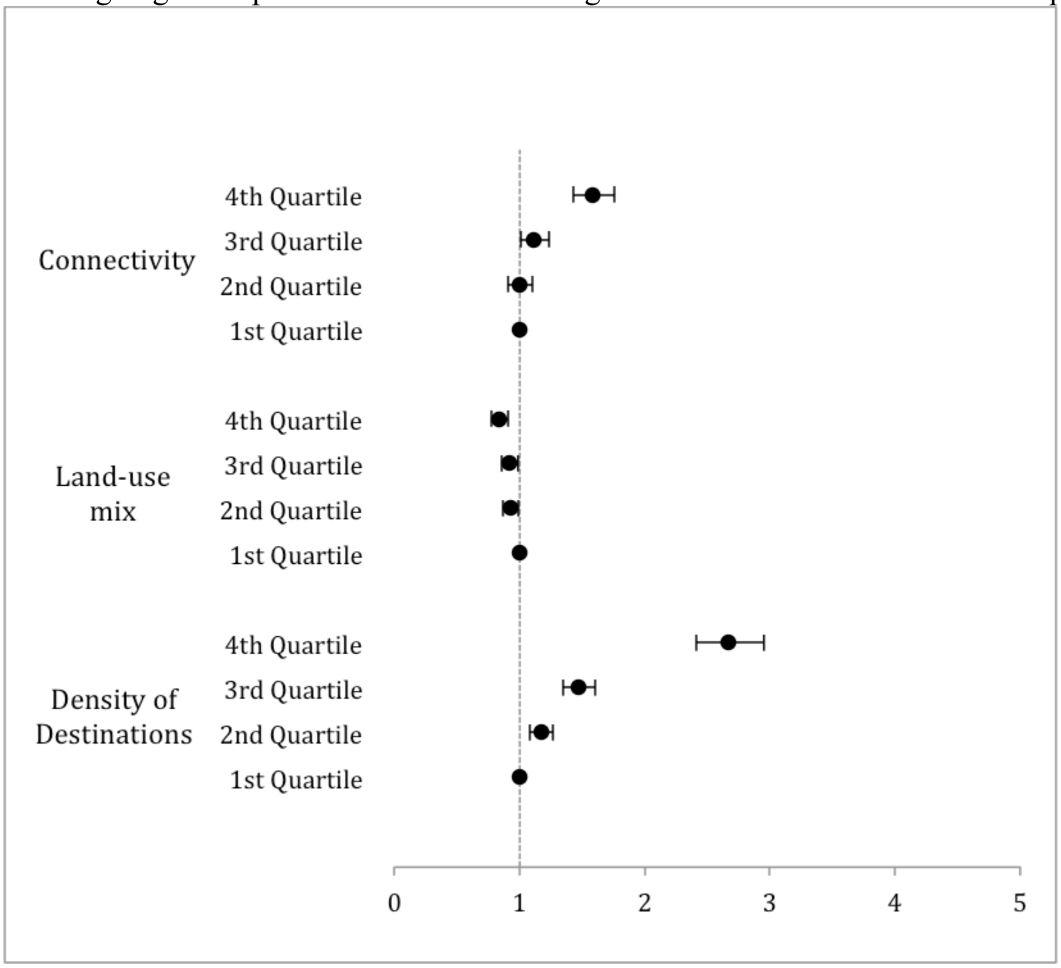


Figure 2: Odd's ratios of the built environment variables for trips where the individual undergoing the trip was from a low SES neighbourhood- in a SES stratified sample.



Conclusion

Synthesis and significance of findings

Previous studies have used built environment measures from the residential neighbourhood to examine the moderating effect of SES on the relationship between the built environment and AT and have obtained equivocal results. In our study, we examined this relationship using a trip level analysis, whereby measures of environmental exposure were derived from the estimated spatial trajectory of individual's trips. The advantages of our approach are that trip route measures of the built environment take into account individual spatio-temporal mobility and may more accurately reflect true environmental exposure. Furthermore, as opposed to conducting analyses using the activity space, trip level analyses may allow for a more accurate prediction of AT by avoiding a loss in measurement precision that may occur during the aggregation of trip level measures.

Our findings indicate that density of businesses and services and connectivity have a weaker association with AT if those undergoing the trip are from a low SES neighbourhood. Previous studies finding no interaction between the built environment and SES may have been due to the limitation of measurements of exposures to the residential neighbourhood. Moreover, our results suggest that there may be social or physical barriers such as poor quality infrastructure, poor quality aesthetics, lack of time, stressful living conditions, and criminality that may prevent low SES residents from taking advantage of health enhancing built environments.

The higher propensity to take AT of individuals from low SES neighbourhoods could compensate for this diminished influence of the built environment on active transportation. Furthermore, the active transport behaviour of those from low SES neighbourhoods was still positively associated with density of destinations and connectivity. Thus, overall our results suggest that modifying the built environment in areas of low SES could still result in increases in active transportation for those of low SES areas. However, further research is needed before policymakers implement this as a strategy to reduce SES inequalities in physical activity. Future studies may want to conduct qualitative research to examine motivations for taking AT, and the social or physical barriers to AT that may exist for individuals of low SES.

A new environmental justice paradigm

Traditionally, environmental justice researchers have advocated for health equity by concerting their research efforts on the investigation of the disadvantaged disproportionate exposure to hazardous environments such as toxic waste sites and their detrimental effects on health. Our research fits into a new environmental justice paradigm that explicitly addresses the consequences of unequal access to health promoting environments (Shortt, Rind, Pearce, & Mitchell, 2014). This paradigm recognizes that engaging in physical activity is not solely dependent on individual choice or "willpower", since the physical environment of a place can both impede or facilitate the maintenance of an active lifestyle (R. E. Lee & Cubbin, 2009). Social inequalities in mobility arise due to inequalities in access, and ability to appropriate ressources, which are conditionned by social context (Kaufmann, Bergman, & Joye, 2004). Thus, environmental injustice not only exists when those of social advantage have greater access to health-enhancing resources but also when the advantaged are better able to take advantage of these resources (R. E. Lee & Cubbin, 2009).

If we wish to achieve health equity we must create interventions that will address the place-based determinants of health of disadvantaged groups. Interventions that target the general population tend to inadvertaintly result in a widening of the gap in physical activity, since advantaged populations are often better able to benefit from programs and policies encouraging health enhancing behaviors (R. E. Lee & Cubbin, 2009). To avoid widening the gap in physical activity, unequal access to good quality physical activity promoting environments should be recognized as an environmental justice issue. Consequently, interventions should be specifically designed to improve the accessibility of these environments for residents of disadvantaged neighborhoods. These interventions should be grounded in the thoughts and experiences of the residents themselves and should promote community empowerment and trust, by having residents take an active role in identifying their needs and barriers to physical activity that will be integrated into the intervention design and implementation process (Blacksher & Lovasi, 2012).

Concluding remarks

Modifying the built environment in disadvantaged neighbourhoods may still be an effective method of addressing the depressed levels of physical activity in disadvantaged communities. However, before attempting to engineer physical activity into the lives of those from low SES areas through means of walkable environments, we urge researchers to first uncover the reasons for the inferior association between the built environment and active transportation in individuals of low SES. This could prevent barriers of the social and physical environments of disadvantaged areas acting as key barriers to the success of interventions.

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Appendix

Appendix I- Chi^2 tests and Spearman's Rank Correlations

Chi2 tests and Spearman's Rank Correlation Coefficients

Analysis

Trips were stratified by neighbourhood socioeconomic status and then by each built environment characteristic separately. Chi^2 tests were performed to determine if the three built environment variables, density of business and services, connectivity, and land-use mix, were independent from neighbourhood SES. Spearman's rank correlation was used to test the association between SES and the built environment variables.

Results

Distributions of each built environment characteristic stratified by neighbourhood SES can be found in appendix tables 1, 2, and 3. Pearson Chi^2 test for density of business and services, connectivity, and land-use mix were significant with values of 1708.797, 5822.181 and 1316.265 respectively. Implying that the three environmental variables are not independent from neighbourhood SES. Spearman's rank correlation for the association between the three environmental variables, density of business and services, connectivity, and land-use mix, and neighbourhood SES was 0.054, 0.168, and 0.075 respectively.

Table 1: Number of trips in each quartile of density and service destinations stratified by the neighbourhood SES of the individual undergoing the trip.

		Neighbourhood SES		Total
		High	Low	
Density of business and services	1st quartile	27777	22520	50297
	2nd quartile	26699	23601	50300
	3rd quartile	21638	28658	50296
	4th quartile	25450	24846	50296
		101564	99625	201189

Table 2: Number of trips in each quartile of connectivity stratified by the neighbourhood SES of the individual undergoing the trip.

		Neighbourhood SES		Total
		High	Low	
Connectivity	1st quartile	31462	18836	50298
	2nd quartile	27161	23137	50298
	3rd quartile	22584	27710	50294
	4th quartile	20357	29942	50299
Total		101564	99625	201189

Table 3: Number of trips in each quartile of land-use mix stratified by the neighbourhood SES of the individual undergoing the trip.

		Neighbourhood SES		Total
		High	Low	
Land-use mix	1st quartile	21530	20572	42102
	2nd quartile	24211	24509	48720
	3rd quartile	27051	26985	54036
	4th quartile	28772	27559	56331
Total		101564	99625	201189