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Neighborhood Sociodemographics and Change in Built Infrastructure

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Abstract

While increasing evidence suggests an association between physical infrastructure in neighbourhoods and health outcomes, relatively little research examines how neighbourhoods change physically over time and how these physical improvements are spatially distributed across populations. This paper describes the change over 25 years (1985–2010) in bicycle lanes, off-road trails, bus transit service, and parks, and spatial clusters of changes in these domains relative to neighbourhood sociodemographics in four U.S. cities that are diverse in terms of geography, size and population. Across all four cities, we identified increases in bicycle lanes, off-road trails, and bus transit service, with spatial clustering in these changes that related to neighbourhood sociodemographics. Overall, we found evidence of positive changes in physical infrastructure commonly identified as supportive of physical activity. However, the patterning of infrastructure change by sociodemographic change encourages attention to the equity in infrastructure improvements across neighbourhoods.

Keywords

neighbourhood; GIS; bicycle; public transportation; race; income

Introduction

The fate of cities is closely linked to the fate of its individual neighbourhoods, with particular neighbourhoods following different change trajectories. Neighbourhoods play an important role in understanding urban transformations. They represent the local arena through which many of these transformations take place, one parcel, one family, one store-front, one park at a time. Most neighbourhoods are dynamic, experiencing constant change.

In a survey of neighbourhoods in metropolitan areas throughout the United States, most were of a very different economic status in 2000 than they were just fifty years earlier (Rosenthal 2008). Demographic and physical changes accompany changes in the economic fortunes of neighbourhood. Transformations have been described as the result of internal and external factors such as the desirability of the housing stock, its amenities, and the rate of change, which interact with exogenous factors to motivate change (Mallach 2008). At the same time, exogenous factors such as immigration, the business cycle, and overall housing supply in an urban area are likely to impact neighbourhoods. More broadly, neighbourhood change is the result of both local, regional, national, and global forces acting on a local level.

The impacts of neighbourhoods on residents are multidimensional. The social and physical structure of neighbourhood contributes to explain resident social capital and social networks. Social and physical neighbourhood characteristics are also frequently discussed for economic development reasons. The physical space is thought of as creating opportunities or inhibiting chance encounters, where information exchange and spillover effects of knowledge-based workers take place. At the same time, planners debate infrastructure improvements such as trails, bicycle lanes, parks, and recreational and cultural amenities that may attract residents belonging to the “creative” class. From a development perspective, neighbourhoods engage in growth, stability, and contraction cycles that heavily impact housing, land uses, and the socio-demographic makeup of residents and visitors. Even for transportation, neighbourhoods are viewed as the areas that can possibly capture most of residents’ non-work travel. This can be especially important for encouragement of pedestrian and bicycle travel, ultimately increasing physical activity and overall health. As a result, during the last two decades investments in infrastructure to facilitate non-automobile travel within neighbourhoods have been popular.

Neighbourhood social conditions have re-emerged as a key social determinant of population health (Diez Roux 2001). A number of investigators have demonstrated links between a neighbourhood’s overall socioeconomic makeup and health outcomes, with residents of neighbourhoods with higher levels of poverty, single-parent households, and other indicators of neighbourhood deprivation faring more poorly on a variety of health outcome measures (Sampson, Morenoff et al. 2002, Messer, Laraia et al. 2006). Neighbourhood disadvantage has been associated with increased chronic kidney disease (Merkin, Roux et al. 2007), diabetes (Schrootman, Andresen et al. 2007, Andersen, Carson et al. 2008, Auchincloss, Roux et al. 2009, Krishnan, Cozier et al. 2010, Müller, Kluttig et al. 2013), metabolic syndrome (Diez Roux, Jacobs et al. 2002, Chichlowska, Rose et al. 2008), and cardiovascular disease (Diez Roux, Merkin et al. 2001, Nordstrom, Roux et al. 2004) and mortality (Kaplan 1997, Diez Roux, Borrell et al. 2004, Jaffe, Eisenbach et al. 2005, Turrell, Kavanagh et al. 2007). Furthermore, Menec (2010) found that the influence of neighbourhoods on health persist into old age; a wide range of health conditions (including arthritis, diabetes, hypertension, congestive heart failure, ischemic heart disease, chronic obstructive pulmonary disease, depression, and stroke) among older adults disproportionately cluster into the poorest areas (Menec, Shooshtari et al. 2010). Some hypothesized mechanisms linking neighbourhood socioeconomic factors to health are housing conditions, violent crime and safety, environmental toxins, social participation or

integration, and potential behavioural differences from built environment opportunities (Northridge, Sclar et al. 2003, Schulz and Northridge 2004).

Among the pathways linking neighbourhood sociodemographic characteristics to health is the physical infrastructure elements of neighbourhoods, including bicycle lanes, bus routes, and parks (Northridge, Sclar et al. 2003, Schulz and Northridge 2004). Studies have investigated links between the neighbourhood physical infrastructure, such as the presence or absence of sidewalks, parks, and other community facilities, both with behaviours linked to health outcomes such as walking (Khattak and Rodriguez 2005, King, Thornton et al. 2012), and a wide range of health outcomes (Potwarka, Kaczynski et al. 2008, West, Shores et al. 2012, Sallis, Spoon et al. 2015). Specifically, presence of parks (Ding, Sallis et al. 2011, Bauman, Reis et al. 2012, Sallis, Floyd et al. 2012), proximity of off-road trails (Sallis, Floyd et al. 2012), bicycling or pedestrian infrastructure (Ding, Sallis et al. 2011, Bauman, Reis et al. 2012, Sallis, Floyd et al. 2012), and public transportation (Bauman, Reis et al. 2012, Sallis, Floyd et al. 2012) have all been shown to be associated with physical activity. In addition, a recent comprehensive review found these features to be associated with a number of co-benefits including physical health, mental health, social benefits, environmental sustainability, and safety (Sallis, Spoon et al. 2015). While increasing evidence suggests an association between neighbourhood built environment infrastructure and health outcomes (specifically physical activity), there has been relatively little study of the way physical, built environment features of neighbourhoods change over time. Even the basic question — how much neighbourhoods change physically — is largely unanswered. Beyond that, though, there is the issue of how physical infrastructure improvements are distributed. What types of neighbourhoods get new or improved infrastructure to encourage physical activity and overall health?

The aims of this paper are two-fold. The first goal is to describe the change over time of particular types of physical infrastructure to encourage physical activity in four United States urban cities that are diverse in terms of geography, size and population. We are particularly interested in how much infrastructure is added over time and where such changes are geographically distributed across the cities. The second goal is to examine the distribution and tempo of changes across social space, with particular attention to sociodemographics of areas with infrastructure changes. This paper approaches these questions by analysing the change in the physical infrastructure within neighbourhoods in four cities in the United States, from 1985 through 2010.

Understanding Neighbourhood Change

Various theories have been used to describe the process of neighbourhood change from a socioeconomic perspective. The political economy theory examines neighbourhood change in the context of different institutions that act in their own self-interests, including real estate developers, real estate agents, insurance agents, and financial lenders. Urban regime theory is one example of how the urban political economy considers the interaction, cooperation, and competition among actors to explain neighbourhood stability and neighbourhood change (Mossberger and Stoker 2001). Regimes are formal and informal durable coalitions involving governmental and non-governmental organizations that come together to achieve

certain tasks and further urban policy agendas. Neighbourhood stability is a by-product of balance among different institutional parties under one or more regimes, in what Imbroscio labelled a dominant urban regime (Imbroscio 1997). If this balance is upset—for example, if property values begin to increase dramatically, then other regimes can begin eroding the power of the existing regime, initiating the process of neighbourhood transformation. For neighbourhoods to survive, then, its residents collectively must compete with these institutional interests “for both resources and influence,” in an effort to maintain neighbourhood coherence (Temkin and Rohe 1996).

Neighbourhood change is driven by, or accompanied by, the exodus of some residents and the influx of others, as well as by the degradation or upkeep of existing private buildings and the construction of new ones. All of this residential change and physical change to *private* property is the responsibility of the residents and landowners. Therefore, for example, studies examining neighbourhood gentrification look at the identities of the departing and arriving residents, and the value of neighbourhood homes, to try to determine how this change occurs, who leaves, and who replaces individuals who move out of the neighbourhood (McKinnish, Walsh et al. 2010, Ellen and O'Regan 2011). Despite their focus on neighbourhood change, these studies pay little attention to the extensive *public* infrastructure provided, including features such as roads and sidewalks, and its changes over time. There are clear consequences to inequitable distribution of infrastructure investment in neighbourhoods. Disparities in infrastructure investments can have significant impacts on such factors as health and community wealth.

In much the same way that the sociodemographic composition of neighbourhoods change, the physical infrastructure of a neighbourhood might be expected to change as well. Over time, infrastructure depreciates or becomes outmoded, requiring investment for repairs or replacement. Infrastructure can also be extended, as a result of new initiatives or priorities. In addition, as best practices change, existing infrastructure might be deemed no longer appropriate. However, while the residents of a neighbourhood can move out and newcomers move in, infrastructure is more permanent. As a result, the process of physical change may be quite different. One key cause of social change in a neighbourhood is the aggregated effect of many hundreds or thousands of individuals or families deciding to move into or out of particular neighbourhoods. Though socioeconomic change can occur as residents living in place either improve or decline in socioeconomic status, these residents still have the option to move out of the neighbourhood. By contrast, physical infrastructure such as roads and parks is fixed in place, and so it is improved or it deteriorates in place. Despite the role that community demands may play in the location and upkeep of infrastructure, the responsibility to maintain, replace, modify or improve this infrastructure lies with government. City or state governments, as part of urban regimes, play an important role in deciding the fate of infrastructure, including what neighbourhoods receive necessary maintenance and enhancements.

Differences in Neighbourhood Infrastructure

Infrastructure investments are not randomly distributed throughout a city's neighbourhoods. They are allocated through the give-and-take of the political process that may advantage

some and disadvantage others (Wolch, Wilson et al. 2005, Joassart-Marcelli 2010). Many factors are expected to influence the distribution of investment, including the general political environment, the local, regional, and state-wide commitment to equity, and the existence of judicial mandates that require equitable distribution of resources (Wood and Theobald 2003). In 1996, Sawicki and Flynn (Sawicki and Flynn 1996) declared that there has been little research into the connection between a neighbourhood's socioeconomic status and its public infrastructure, a research gap that still remains.

There are several potential mechanisms that might connect a neighbourhood's sociodemographic characteristics with the investment in its public infrastructure. For example, neighbourhoods in which the average resident has a higher income level or more education than the rest of the city may be more successful in convincing city government to place certain amenities such as sports fields or bicycle lanes in their neighbourhoods. Other research has found connections between rates of homeownership and indicia of community involvement such as knowledge of local political representatives and membership in local nonprofessional organizations, as well as between length of residence in a community and those same community variables (DiPasquale and Glaeser 1999, Manturuk, Lindblad et al. 2012). Moreover, homeowners' equity in their property provides them with an obvious financial incentive to involve themselves in local initiatives that could depress or increase property values. Therefore, it is plausible that stable neighbourhoods with a high number of homeowners or long-term renters will leverage their heightened involvement in local affairs into actions that increase government investment in neighbourhood infrastructure such as parks and transit service. If true, the increased mobility of the poor, and their higher concentration in higher-poverty neighbourhoods, would contribute to this effect. On the other hand, political power may be won by coalitions that include the dispossessed and disadvantaged, such as the urban regimes with an equity agenda. To hold their grip on political power, these coalitions may shift spending on investments like new parks and bus services to their constituents' neighbourhoods, while neglecting others (Sawicki and Flynn 1996).

Due, in part, to residential segregation, the geographic patterns of infrastructure, particularly green space or trail investment, may be inequitable in terms of racial and socioeconomic neighbourhood composition. Research has generally found that disadvantaged groups are more likely to live in places with fewer locations to be physically active (Tarrant and Cordell 1999, Timperio, Ball et al. 2007, Crawford, Timperio et al. 2008, Lovasi, Hutson et al. 2009, Smiley, Roux et al. 2010, Billaudeau, Oppert et al. 2011, Duncan, Kawachi et al. 2013), although some work suggests that there are "reverse" disparities with better access for disadvantaged groups (e.g. increased access to facilities that promote physical activity) (Talen 1997, Tarrant and Cordell 1999, Moore, Diez Roux et al. 2008, Boone, Buckley et al. 2009, Cutts, Darby et al. 2009, Franzini, Taylor et al. 2010, Billaudeau, Oppert et al. 2011). The process by which new infrastructure is distributed across sociodemographic characteristics such as race, education or income may represent a historic pattern of residential segregation or differences in power dynamics and urban regimes. Regardless, race and socioeconomic status play important roles as fundamental determinants of neighbourhood investment that must be considered when examining infrastructure change.

In summary, the vast majority of literature on neighbourhood change has focused on the sociodemographic and housing characteristics of the neighbourhood rather than infrastructure and the built environment. Theories of neighbourhood change focus on the neighbourhood dynamics, the social power of groups within these neighbourhoods and the interplay between resident's preferences, demands, and residential choices. Despite the importance of infrastructure change for the fate of neighbourhoods and the health of individuals within those neighbourhoods, little is known about how neighbourhood infrastructure changes over time. Additionally, even less is known about how those changes vary across neighbourhoods and how they may relate with socio-demographic conditions of neighbourhood residents. This study aims to fill this gap by examining change in key health-promoting infrastructure (parks, bicycle facilities, off-road trails, and public transportation) across four diverse U.S. cities. Due to recent attention and funding, we anticipate increases in all of these features. In light of the interplay between infrastructure and both the neighbourhood and the residents who live there, we expect these changes to be patterned by sociodemographic characteristics such that positive changes in infrastructure occur in neighbourhoods also experiencing increasing socioeconomic conditions.

Methods

Data

We focus on four cities within Metropolitan Statistical Areas (MSAs) as defined by the 2010 population census: Birmingham AL, Chicago IL, Minneapolis MN, and Oakland, CA. These cities are diverse in terms of geography, size and population diversity, making them ideal to understand neighbourhood infrastructure change and for analysing whether particular sociodemographic factors are associated with infrastructure changes. The neighbourhood boundaries used in this research (n=387) were assembled from two data sources: Chicago, Minneapolis, and Oakland neighbourhood boundaries are publicly available from Zillow.com (www.zillow.com/howto/api/neighborhood-boundaries.htm) and boundaries for Birmingham neighbourhoods were obtained from the Regional Planning Commission of Greater Birmingham (www.rpcgb.org). These boundaries represent conceptually-defined neighbourhoods, created by Zillow in an iterative process involving company employees, real estate agents, chambers of commerce, tourism and convention boards, and other professionals familiar with each city. To maintain constant boundaries throughout the study period, all data were normalized to these neighbourhoods.

To collect retrospective and contemporary data on the timing and placement of introductions, renovations, and closures of recreation facilities (e.g., trails, parks) and transportation infrastructure (e.g., light rail, bicycle parking, bicycle paths) from 1985 through 2010, research assistants visited the four cities in the spring and summer of 2012. Our database of built environment features over time was constructed from current and historic geospatial data, historic documentation including maps (e.g., bus and bicycle routes), Capital Improvement Plans (CIPs), and Transportation Improvement Plans (TIPs), and personal communication with local stakeholders and experts in each city. The presence, location, size, and attributes of all features are represented on a yearly scale in the database. To the extent possible, we documented additions, removals, and significant changes of

features throughout the study period, as well as attributes and amenities of each feature, though complete historic information dating to 1985 was not available for all features in all cities. Features were assumed to remain stable until we noted a documented addition, removal or significant change. Additional details including the protocol for the collection and processing of the built environment data and the specific dates for CIPs and TIPs used for each city can be found elsewhere (Hirsch, Meyer et al. 2016).

Infrastructure Measures

The field audited data for bicycle lanes, off-road trails, bus transit service, and parks were measured relative to the neighbourhoods in each city using ArcGIS 10.2.1 (ESRI, Redlands, CA). Bicycle lanes and recreational trails were measured by their total length accessible from each neighbourhood (defined as within the neighbourhood), the availability of bus transit service assessed as the percentage of total street length which is served by one or more transit bus routes, and the characterization of park significance to neighbourhoods based on the number of parks, the number of parks with community centres present, area of parks within the neighbourhood (hectares) and the number of positive park changes (addition or refurbishing of park amenities) since the previous year. Rail was not included since one city did not have any rail infrastructure, and two cities experienced no significant changes in their rail systems over the study period. All measures were assessed as time varying by year, with lengths measured in meters. To account for the estimated total width of traffic and parking lanes which might separate two adjacent neighbourhoods, all features within 23 meters (75 feet) of a neighbourhood boundary were attributed to all the neighbourhoods sharing that common boundary.

Sociodemographic Measures

Neighbourhood sociodemographic data included: percentage of population below the poverty line, percentage of labour force unemployed, neighbourhood household median income, percent of housing occupied, and percent non-Hispanic white. Sociodemographic data were taken from the U.S. Census Bureau decennial population censuses for 1980, 1990, and 2000 and from the American Community Survey, 2006–2010 and 2007–2011 five-year estimates. Tract-level data was assigned to neighbourhoods based on the proportion of each tract that overlapped each neighbourhood, as measured by land area; these calculations were performed using ArcGIS version 10.0 Service Pack 5 software (ESRI, Redlands, CA), 1980 and 1990 tract boundaries prepared by the National Historical Geographic Information System (Minnesota Population Center 2011), and 2000 and 2010 tracts available from ESRI Data and Maps. Because the Census changed its data reporting each decade, variables were cross-walked and aggregated as necessary to enable comparability over time.

Statistical Analysis

Descriptive statistics were calculated for all neighbourhood infrastructure and sociodemographic variables in 1985 and average changes per 10 years for the full sample and by city. Change in the built environment infrastructure was examined spatially within each study area using a first-order, row-standardized, rook contiguity definition of neighbourhoods; sensitivity analyses using a row-standardized, Euclidean, inverse distance definition of neighbourhoods produced similar results (not shown). Global Moran's I was

used to measure overall clustering of change and Local Moran's I was used to identify statistically significant clusters of high increases surrounded by high increases. Sociodemographic characteristics were compared between high increase clusters surrounded by high increases and neighbourhoods that were not in these high increase clusters (including tracts in low-low, high-low, and low-high clusters) using t-test or chi-square tests, as appropriate.

Linear mixed models were used to estimate the associations of changes in sociodemographic characteristics with changes in infrastructure. Infrastructure demonstrating minimal change in descriptive statistics were not examined in future models. A full description of model specification and explanation of terms can be found in supplemental material (Table S1). Briefly, we modelled infrastructure measures over time in each neighbourhood as a function of baseline sociodemographic measures, time in years since baseline (to capture the change in infrastructure over the study), a term for the interaction between baseline sociodemographic measures and time (potential impact of baseline sociodemographic on changes in infrastructure over time), change in sociodemographic since baseline (necessary to interpret the interaction between this variable and time), an interaction term between change in sociodemographic since baseline and time (to capture how changes in sociodemographics affect changes in infrastructure over follow-up), and both time-invariant (city, land area) and time-varying (population) independent variables. All models included a random intercept and random time slope for each neighbourhood to allow the baseline responses and the time slope to vary between neighbourhoods. City was included as a fixed effect. Since variance inflation factors for all of the sociodemographic characteristics were below 10 (indicating no collinearity), these predictors were included simultaneously in one model. Sensitivity analyses were performed for each sociodemographic variable separately; results were substantively consistent (not shown).

Results

Overall, neighbourhoods started with a mean of 136.03 meters of bicycle lanes (standard deviation (SD) 498.64) and 449.96 meters (SD 1080.92) of off-road trails (Table 1) and experienced increases in both infrastructure elements. Birmingham had the lowest baseline total length of (and increases in) bicycle lanes while Chicago had the highest initial levels. Minneapolis experienced the highest increases in total length of bicycle lanes and off-road trails during this time period. On average, 20.22% (SD 10.07%) of streets had bus service coverage and this increased by 0.32% (standard error (SE) 0.02%). Minneapolis also experienced the highest increases in percent of streets covered by bus transit. Overall, neighbourhoods across all cities had fairly low counts of parks, community centres and fewer positive park changes from the previous years. Among the four cities, Oakland and Birmingham had the lowest park counts and the lowest change in parks, while Chicago had the highest levels and changes. All cities experienced minimal increases in area of parks within each neighbourhood. Since there were few to no changes in park metrics across the cities, we did not examine predictors of these infrastructure changes in multilevel or spatial models. Changes over time were heterogeneous both within and between cities, with the amount of variability differing by infrastructure features (Supplemental Figures S1–S4).

For sociodemographics, on average, neighbourhoods started with an average of 19.50% (SD 12.90%) of residents below the poverty line and 9.59% (SD 5.72%) unemployed labour force and saw increases in both of these socioeconomic indicators (Table 1). Overall, median household income increased across all cities, while percent of occupied housing and percent non-Hispanic White declined. In general, Birmingham had lower socioeconomic status with higher percent below the poverty line, greater increases in unemployment, and lower initial and smaller increases in median household income. Birmingham and Oakland started with the lowest percent non-Hispanic White, while Minneapolis started with the highest. However, Oakland was the only city to experience an increase in percent non-Hispanic White (1.82% per 10 year increment, SE 0.11) over this time period. Across all socio-demographic indicators except for household income, Chicago exhibits the highest heterogeneity.

Across all four cities, Global Moran's I results for bicycle lanes, off-road trails, and bus transit service were positive and significant (Table 2), indicating that the spatial distribution of high or low values was more spatially clustered than would be expected if underlying spatial processes were random. However, many were small in magnitude, indicating only minimal spatial clustering. Chicago experienced higher clustering of bicycle lanes, while Minneapolis experienced higher clustering of off-road trails, and Oakland experienced higher clustering of bus transit service. Local Moran's I identified 22, 24, and 22 neighbourhoods in clusters of high increase in bicycle lanes, off-road trails, and bus transit service, respectively (Table 3, Supplemental Figures S5–S7). Neighbourhoods in clusters of high increase in bicycle lanes had lower initial percent occupied housing in 1985 and decreases in percent unemployed population (as compared to increases), higher increases in median household income, and smaller decreases in percent occupied housing between 1985 and 2010 than neighbourhoods not in these clusters. Compared to neighbourhoods not clustered for off-road trail changes, neighbourhoods in clusters of high increase in off-road trails had higher percent non-Hispanic white in 1985 and those in clusters of high increase in bus transit service remained stable in unemployment between 1985 and 2010, rather than increasing percent unemployed.

Estimated associations between baseline sociodemographic characteristics and change in sociodemographic characteristics on mean changes over time in infrastructure are in shown Table 4. The time trend represents the change over time in a given infrastructure; overall, bicycle lanes increased an average of 125.98 meters per year (95% confidence interval (CI) 111.29, 140.67), off-road trails increased an average of 18.02 meters per year (CI 13.31, 22.74), and percent of streets serviced by bus transit increased slightly (0.07% per year, CI 0.05, 0.09).

Baseline sociodemographics represent the cross-sectional association with mean level of infrastructure at baseline. Adjusting for relevant covariates and all other sociodemographics, neighbourhoods with higher initial unemployment and higher percent non-Hispanic white had lower initial levels of bicycle lanes. However, neighbourhoods with one standard deviation higher baseline median household incomes had 177.16 additional meters of bicycle lane (CI 51.59, 302.73). Neighbourhoods with higher baseline percent below the poverty line started out with significantly lower off-road trails (mean difference for a

baseline standard deviation in percent below the poverty line -282.78 meters CI -524.13 , -41.42). Neighbourhoods with higher baseline percent population below the poverty line had a higher percent of streets covered by bus transit, while those with higher percent unemployed, median household income, and occupied housing all had lower percent of streets covered by bus transit.

To understand the estimates for interactions between sociodemographics and time, add the estimate for a given interaction to the time trend. Neighbourhoods with higher baseline poverty and percent non-Hispanic White experienced steeper increases in bicycle lanes while neighbourhoods with higher percent occupied housing experienced slightly smaller increases in bicycle lanes (mean change for a standard deviation increase in baseline percent occupied housing -19.72 meters less per year, CI -36.91 , -2.53). Neighbourhoods experiencing increases in percent of the labour force unemployed and percent occupied housing experienced slightly smaller increases in total length of bicycle lanes. Similarly, neighbourhoods experiencing increases in median household income experienced larger increases in total length of bicycle lanes (mean increase of 21.40 additional meters per year for one standard deviation increase in median household income, CI 18.60 , 24.19). Increases in off-road trails were larger in neighbourhoods with higher baseline percent below the poverty line and higher baseline median household income (mean increase of 16.06 (CI 7.35 , 24.78) and 17.26 (CI 10.71 , 23.81) additional meters per year for one standard deviation difference in baseline percent below the poverty line and baseline median household income, respectively). Off-road trail increases were slightly smaller in neighbourhoods experiencing increases in percent below the poverty line, increases in percent unemployed, and increases in non-Hispanic white population. Neighbourhoods with higher baseline percent below the poverty line and percent non-Hispanic white experienced greater increases in bus transit coverage. Conversely, neighbourhoods with increases in median household income saw greater increases in bus transit while neighbourhoods with increases in percent occupied housing had smaller increases in bus transit.

Discussion

As attention turns toward the potential of built environment infrastructure elements to increase the liveability, sustainability, and environmental and human health of communities, this study finds evidence that in the previous 25 years, across four diverse U.S. urban cities, positive changes have taken place. For transportation-related behaviours, bicycle lanes and bus service have increased. Although few changes were identified in neighbourhood park infrastructure, increases in total length of off-road trails show promise. However, changes in these infrastructure elements were spatially clustered and patterned by neighbourhood sociodemographic characteristics; neighbourhoods experiencing increases in bicycle lanes, off-road trails, and bus transit service often also experienced increases in indicators of socioeconomic affluence.

Increases observed in some of the infrastructure elements examined are consistent with the significant time and resources invested by these cities in recent years. Between 1985 and 2011, the City of Chicago spent more than \$41 million on bicycle facilities, with plans to spend at least \$40 million more on combined bicycle and park facilities by 2015 (Chicago

Department of Transportation 2012). Meanwhile, Oakland earmarks five percent of tax revenues for bicycle and pedestrian projects, amounting to roughly \$1 million per year, with 10% devoted solely to bicycle lanes and facilities (Community and Economic Development Agency 2008). Differences in the level of change across the four cities were also as expected: with Minneapolis experiencing the greatest increase in bicycle lanes while Birmingham experienced the smallest. This is encouraging as Minneapolis was awarded money from the Nonmotorized Transportation Pilot Program (Federal Highway Administration 2014), a \$25 million project launched in 2005 to make biking and walking infrastructure a priority of transportation planning. Unfortunately, while the Regional Planning Commission of Greater Birmingham proposed a network of on and off-road facilities in the 1996 Birmingham Area Bicycle, Pedestrian & Greenway Plan, many goals have seen little progress and are being revisited during the development of a new 2035 Regional Transportation Plan (Regional Planning Commission of Greater Birmingham 2015). Similarly, it is important to note the heterogeneity in allocation of resources and new infrastructure. Despite overall increases in many infrastructure elements, we observed variability in the change across the cities, by neighbourhood within city, and by infrastructure type. Similarly, higher clustering of changes was seen in different cities: bicycle lanes in Chicago; off-road trails in Minneapolis; and bus transit service in Oakland. This heterogeneity may be due to differences in amount of resources a city has, the political power of select neighbourhoods, or even the physical logistics of adding an infrastructure feature due to density or space restrictions. Nonetheless, popular support suggests that overall increases in these features may continue; a recent national survey of likely 2016 voters found that 31% would prefer to increase federal funding for walking and biking paths and 64% believed that walking and biking paths are very affordable to build and provide billions of dollars in fuel and health care savings nationally each year (Rails-to-Trails Conservancy 2014).

Our research did not, however, pick up the substantial resources that have also been devoted to park facilities during the same timeframe. Between 1985 and 2011, the City of Chicago also spent more than \$1 billion in current dollars on park facilities (Chicago Department of Transportation 2012). During fiscal year 2009, Chicago, Minneapolis and Oakland spent more than \$379 million, \$76 million and \$53 million, respectively, on park facilities (The Trust for Public Land 2011). Further south, in 2010 the City of Birmingham, Alabama spent more than \$26 million into capital investment for its parks system (City of Birmingham 2010). Discrepancies may be due, in part, to the amount of time necessary to create new parks or renovate existing ones. Alternatively, limited park funds may be distributed across maintenance costs rather than used to build or upgrade parks, the two measures used in this study. For example, in Minneapolis, the 2015 budget indicated that between 2000–2014, the neighbourhood capital park program was underfunded by over \$110 million dollars (Minneapolis Park & Recreation Board 2015). It states, “The long-term underfunding of both operating and capital has created an unsustainable funding model for Minneapolis Park & Recreation Board neighbourhood parks. With current resources, only a very small number of necessary construction projects are funded annually and only essential maintenance or emergency repairs are able to be completed” (Minneapolis Park & Recreation Board 2015).

There was some spatial clustering of changes in bicycle lanes, off-road trails, and bus service within each city. This is aligned with the idea that infrastructure changes occur in interconnected networks to create an efficient transportation system. However, the lower spatial clustering may indicate that resources for improvements may be distributed based on other factors. While changes in other built environment elements, such as food stores or physical activity destinations, would follow market patterns, infrastructure like bicycle lanes may be more limited. That is, there are only so many streets to add bicycle lanes to. Similarly, current spatial methods did not allow us to incorporate initial levels of development when examining clustering in infrastructure change. Thus, places receiving more new infrastructure may be neighbourhoods with more potential for change. In addition, these infrastructure features are planned at the city level, perhaps resulting in more intentional (and thus less spatially clustered) pattern. Local spatial indicators give more insight into spatial clustering. Larger increases in bicycle lanes tended to occur in dense, urban centres with the exception of Oakland, which also exhibited large increases in bicycle lanes in parts of the city closer to natural features. By contrast, larger increases in off-road trails occurred on the edges of these cities where there is room to develop trails and connect them to natural amenities.

As expected, neighbourhood sociodemographic characteristics were associated with neighbourhood infrastructure change. Neighbourhoods with higher baseline poverty in 1985 experienced higher baseline bus service and higher increases in bus service between 1985 and 2010. While neighbourhoods with higher unemployment had lower baseline bus service, neighbourhoods in clusters of high increases in bus service experienced stable (versus increasing) unemployment rates over the time period. These results may indicate that neighbourhoods starting out with lower initial bus service had restricted opportunities for employment due to limited transit options to employment subcentres. Neighbourhoods in clusters with increased bus service over time may also have provided transit to employment opportunities necessary to resist the surge in unemployment experienced by other neighbourhoods during the Great Recession. Similarly, neighbourhoods in clusters of increases in bicycle lanes experienced decreases rather than increases in unemployment over the time period (negative association between unemployment and bicycle lanes). In regression models we also observed slightly smaller increases in bicycle lanes for places experiencing increased unemployment over time. This could be due to places with decreasing economic resources having less money to add bicycle lanes. Alternately, these bicycle lanes may have provided the critical infrastructure necessary to connect residents of these neighbourhoods to employment opportunities, as previous work suggests bicycle lanes are primarily used by commuters (Dill and Carr 2003).

Income tells a similar story; in both spatial patterns and multi-level models, neighbourhoods with larger increases in median household income were also the neighbourhoods with larger increases in bicycle and bus infrastructure. Both our unemployment and income results suggest the potential for transit and bicycle infrastructure investments to positively affect the economic well-being of a neighbourhood. These results are consistent with previous literature that housing prices are higher or increase with new trails or greenbelts (Asabere and Huffman 2009), bicycle facilities (Krizek 2006), and public transit (Bowes and Ihlanfeldt 2001) or transit-oriented development (Bartholomew and Ewing 2011). In conflict

with these results, we observed that areas experiencing infrastructure investments started with lower percentage occupied housing. Similarly, places that had increases in occupied housing experienced smaller increases in bicycle lanes. This could be due to the physical demands or requirements of placing new infrastructure, as new infrastructure can only be placed where there is space. Nonetheless, places experiencing infrastructure investments had less decrease in occupied housing, which is still aligned with previous work on the economic benefit of new trails or greenbelts. With all of these associations, it is impossible to determine temporality in these relationships; areas with stronger economic capacity may have been able to leverage more support for bus and bicycle infrastructure. Alternatively, neighbourhoods with increases in transit and bicycle infrastructure may have experienced social or economic change that drew new residents with subsequent demand for new infrastructure elements. As suggested by the various theories and approaches to understand neighbourhood change, these processes are intertwined and reciprocal; new infrastructure can feed economic development and attract new types of residents who may demand greater infrastructure support.

The patterning of infrastructure change with sociodemographic change may play an important role in equity and health disparities. The implications of wealthier, more stable neighbourhoods receiving infrastructure improvements could increase health disparities if they result in changes in health behaviours (Cerin, Leslie et al. 2009). The increases we found in infrastructure and socioeconomic status are consistent with previous cross-sectional literature that low-income and minority neighbourhoods have worse aesthetics or safety (Lovasi, Hutson et al. 2009) and fewer opportunities for physical activity (Abercrombie, Sallis et al. 2008). Our result on the racial composition of neighbourhoods experiencing increases in trails is also consistent with evidence that non-Hispanic white neighbourhoods have better access to recreational opportunities (Smiley, Roux et al. 2010). However, some evidence suggests that disadvantaged neighbourhoods actually may be more walkable (i.e., shorter block length, greater street node density, more developed land use, and higher density of street segments) (King and Clarke 2014). This aligns with our findings for bus transit that areas with better bus access actually had lower initial median incomes and lower initial occupied housing. While there is still too limited information to concretely discuss the direct role of built environment changes on health disparities, careful attention should be paid to equity in plans for proposed infrastructure improvements.

Although we used longitudinal data, environmental audits and GIS data from municipalities may not perfectly represent the physical environment at all times. Similarly, although we used Census variables that remained fairly consistent over the study period, some inconsistencies may arise from combining decennial Census and the American Community Survey data due to their fundamentally differing sampling designs. Additionally, underlying social and planning processes that result in changes may be longer than the time period studied or exist at a different geographic scale. It is also unclear whether the geographic unit studied is the most appropriate when considering the potential for these types of infrastructure changes to influence health behaviours or health disparities. There may be residual confounding by other variables at the neighbourhood level or higher, including exogenous economic factors such as the Great Recession. The four U.S. cities analysed in this paper represent three distinct geographic contexts (Midwest, south, and west coast),

however, results may not be generalizable to other U.S. cities or contexts. Further research in other geographies, at other scales, and across other levels of development, especially rural, would give additional insight into broader infrastructure changes nationally.

Conclusion

This is one of the first studies to document recent changes in built environment infrastructure elements and the sociodemographic characteristics associated with these changes at the neighbourhood level. We identified increases in bicycle, bus service, and off-road trails in a sample of four diverse U.S. urban cities. Increasing support for pedestrian- and transit-oriented development appear to be reflected in positive changes that allow for liveable and more sustainable communities, and for increased physical activities of residents. The clustering of these changes in neighbourhoods with higher median incomes or lower unemployment may have important implications for environmental equity and subsequent health disparities. In particular, we found increases in socioeconomic conditions in neighbourhoods experiencing positive changes in infrastructure. This may reflect the added economic value of these new infrastructure or it may reflect a process by which neighbourhoods with quickly changing social composition and growing economies leverage support for physical changes. Increased collaboration across disciplines can assist in the design of urban planning solutions that can be implemented by local governments to improve health equity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Built Environment Infrastructure Features and Socioeconomic Characteristics at Baseline (1985) and Mean Change Per Each 10-Year Increment, Overall and by Site, Four Cities Study, 1985–2010.

Neighbourhoods	Overall (n=387)		Birmingham (n=95)		Chicago (n=77)		Minneapolis (n=84)		Oakland (n=131)	
	Baseline Mean (SD)	Mean Change ^d (SE)	Baseline Mean (SD)	Mean Change ^d (SE)	Baseline Mean (SD)	Mean Change ^d (SE)	Baseline Mean (SD)	Mean Change ^d (SE)	Baseline Mean (SD)	Mean Change ^d (SE)
Infrastructure:										
Bicycle Lanes (meters)	136.03 (498.64)	867.24 (14.86)	8.20 (60.37)	17.54 (2.43)	388.42 (902.82)	1559.56 (51.44)	123.79 (397.82)	1717.68 (30.82)	88.24 (325.58)	531.16 (14.67)
Off-road Trails (meters)	449.96 (1080.92)	138.25 (4.61)	316.87 (1138.47)	18.29 (1.78)	800.43 (1157.19)	6.47 (1.51)	760.30 (1304.68)	494.62 (16.66)	141.47 (646.95)	74.21 (6.17)
Bus Transit Service ^b (%)	20.22 (10.07)	0.32 (0.02)	13.75 (9.28)	0.17 (0.04)	17.92 (5.41)	0.17 (0.02)	22.50 (8.86)	0.77 (0.07)	24.79 (10.64)	0.23 (0.04)
Parks (count)	3.28 (3.82)	0.10 (0.00)	1.57 (1.55)	0.06 (0.00)	8.58 (4.86)	0.24 (0.01)	3.38 (2.27)	0.07 (0.01)	1.34 (1.38)	0.05 (0.00)
Parks with Community Centres (count)	0.07 (0.26)	0.11 (0.00)	0.00 (0.00)	0.02 (0.00)	0.00 (0.00)	0.07 (0.01)	0.01 (0.11)	0.31 (0.01)	0.20 (0.40)	0.07 (0.00)
Park area (hectares)	16.17 (32.61)	0.27 (0.02)	13.17 (42.88)	0.22 (0.02)	35.89 (36.96)	0.58 (0.08)	17.37 (22.54)	0.13 (0.03)	5.97 (19.02)	0.21 (0.04)
Positive Park Changes from Previous Year (count) ^c	0.92 (1.53)	−0.02 (0.01)	0.40 (0.67)	−0.02 (0.01)	1.81 (2.03)	0.08 (0.02)	1.62 (1.93)	−0.14 (0.02)	0.32 (0.72)	−0.01 (0.01)
Sociodemographics ^d :										
Percent below poverty line	19.50 (12.90)	0.80 (0.05)	23.47 (12.44)	1.52 (0.09)	20.03 (15.85)	0.49 (0.12)	16.38 (13.26)	1.48 (0.11)	18.30 (10.19)	0.02 (0.06)
Percent of labour force unemployed	9.59 (5.72)	0.83 (0.03)	9.87 (4.36)	1.82 (0.07)	11.57 (7.08)	0.56 (0.07)	6.17 (4.02)	1.07 (0.06)	10.42 (5.74)	0.13 (0.05)
Median household income (in thousands)	20.93 (10.05)	12.47 (0.09)	15.80 (6.46)	7.94 (0.12)	21.56 (7.28)	11.21 (0.15)	21.50 (7.74)	13.59 (0.17)	23.91 (13.10)	15.77 (0.21)
Percent occupied housing	93.39 (3.68)	−2.49 (0.04)	92.30 (2.48)	−4.79 (0.07)	92.92 (4.34)	−2.64 (0.08)	94.77 (3.83)	−1.23 (0.07)	93.58 (3.62)	−1.54 (0.06)
Percent non-Hispanic White	49.64 (34.94)	−3.06 (0.09)	37.63 (33.50)	−6.21 (0.21)	50.23 (38.25)	−4.35 (0.21)	83.66 (17.76)	−5.93 (0.18)	36.19 (26.84)	1.82 (0.11)

Abbreviations: SE, standard error; SD, standard deviation.

^aMean change was determined using a multi-level random-effects model of change in each built environment measure since baseline regressed on time in decades (10-years), with random intercepts for each neighbourhood

^bPercentage of streets with bus service

^cPositive park changes from the previous year at baseline represent changes reported for the year up to 1985.

^dSociodemographic data were taken from the U.S. Census Bureau decennial population censuses for 1980, 1990, and 2000 and from the American Community Survey, 2006–2010 and 2007–2011 five-year estimates

Overall spatial clustering of change in built environment infrastructure between 1985 and 2010 in four U.S. cities. Four Cities Study, 1985–2010

Table 2

	Bicycle Lanes ^a		Off-road Trails ^a		Bus Transit Service ^{a,b}	
	Global Moran's I ^c	P-value	Global Moran's I ^c	P-value	Global Moran's I ^c	P-value
Birmingham (n=95)	0.1046	0.0254	0.1509	0.003882	0.2580	0.00004
Chicago (n=77)	0.3687	<0.0001	0.1385	0.000131	0.1323	0.014559
Minneapolis (n=84)	0.2071	0.001585	0.4197	<0.001	0.2167	0.000947
Oakland (n=131)	0.2044	0.000149	0.1222	0.008673	0.3964	<0.0001

^aChange in each infrastructure between 1985 and 2010.

^bPercent of neighbourhood streets covered by bus transit service

^cCalculated by city with a first-order, row-standardized, rook contiguity definition of neighbourhoods.

Table 3

Sociodemographic characteristics of neighbourhoods in spatial clusters of high change in built environment infrastructure derived from Local Moran's I between 1985 and 2010 in four U.S. cities, Four Cities Study, 1985–2010

	Bicycle Lanes ^{b,c}				Off-road Trail ^{b,c}				Bus Transit Service ^{b,d}			
	High Change Cluster ^e		Other ^e		High Change Cluster ^e		Other ^e		High Change Cluster ^e		Other ^e	
	Mean (SD)	Mean (SD)	P-value		Mean (SD)	Mean (SD)	P-value		Mean (SD)	Mean (SD)	P-value	
N	22	365			24	363			22	365		
Baseline in 1985:												
Percent below poverty line	24.72 (14.29)	19.18 (12.77)	0.0503		20.66 (14.29)	19.42 (12.83)	0.6493		19.24 (12.47)	19.51 (12.95)	0.9220	
Percent of labour force unemployed	10.04 (7.07)	9.57 (5.63)	0.7052		8.34 (6.27)	9.68 (5.68)	0.2686		10.56 (7.45)	9.53 (5.60)	0.5311	
Median household income (in thousands)	20.58 (12.59)	20.95 (9.89)	0.8666		20.39 (9.98)	20.97 (10.06)	0.7861		23.37 (15.95)	20.78 (9.59)	0.4606	
Percent occupied housing	90.61 (5.31)	93.56 (3.50)	0.0174 [*]		92.36 (4.98)	93.46 (3.57)	0.2984		93.35 (3.85)	93.39 (3.67)	0.9568	
Percent non-Hispanic White	53.99 (31.33)	49.38 (35.17)	0.5488		63.80 (32.05)	48.70 (34.96)	0.0402 [*]		47.68 (40.06)	49.76 (34.67)	0.7870	
Change between 1985 and 2010:												
Percent below poverty line	0.18 (11.62)	2.99 (8.08)	0.2748		3.06 (10.75)	2.81 (8.16)	0.9145		1.02 (8.09)	2.94 (8.34)	0.2946	
Percent of labour force unemployed	-0.86 (4.39)	3.10 (5.12)	0.0004 ^{**}		2.56 (4.38)	2.90 (5.21)	0.7604		0.41 (6.09)	3.02 (5.07)	0.0209 [*]	
Median household income (in thousands)	42.55 (26.22)	29.44 (21.13)	0.0056 ^{**}		30.39 (18.56)	30.17 (21.84)	0.9627		42.03 (34.93)	29.47 (20.41)	0.1095	
Percent occupied housing	-3.48 (6.33)	-6.72 (6.29)	0.0191 [*]		-4.57 (7.04)	-6.67 (6.27)	0.1153		-7.38 (5.00)	-6.49 (6.40)	0.5228	
Percent non-Hispanic White	0.29 (14.91)	-7.86 (19.18)	0.0512		-8.88 (18.00)	-7.30 (19.12)	0.6931		-3.87 (15.07)	-7.61 (19.25)	0.3717	

Abbreviations: SD, Standard Deviation

* <0.05;

** <0.01;

*** <0.0001

^g Sociodemographic data were taken from the U.S. Census Bureau decennial population censuses for 1980, 1990, and 2000 and from the American Community Survey, 2006–2010 and 2007–2011 five-year estimates

^h Change in each infrastructure between 1985 and 2010.

ⁱ In meters

^j Percent of neighbourhood streets covered by bus transit service

^e Clusters of high change in each infrastructure identified using Local Moran's I by city with a first-order, row-standardized, rook contiguity definition of neighbourhoods. "High change clusters" represent neighbourhoods with high increases, surrounded by high increases. "Other" includes decreases or low increases surrounded by decreases or low increases, discordant neighbourhoods, or non-clusters (not statistically significant).

Table 4

Estimated Associations of Baseline Sociodemographic Characteristics (1985) and Change in Sociodemographic Characteristics on Mean Changes over Time in Built Environment Infrastructure. Four Cities Study, 1985–2010

	Bicycle Lanes ^{a,b} Estimate (95% CI)	Off-road Trails ^{a,b} Estimate (95% CI)	Bus Transit Service ^{a,c} Estimate (95% CI)
Time trend	125.98 (111.29, 140.67) ***	18.02 (13.31, 22.74) ***	0.07 (0.05, 0.09) ***
Baseline Sociodemographics:			
Percent below poverty line	97.82 (-78.89, 274.52)	-282.78 (-524.13, -41.42) *	3.79 (1.83, 5.76) **
Percent of labour force unemployed	-192.73 (-376.08, -9.37) *	-20.43 (-276.10, 235.23)	-4.57 (-6.65, -2.49) ***
Median household income	177.16 (51.59, 302.73) **	69.02 (-103.30, 241.33)	-1.95 (-3.35, -0.54) **
Percent occupied housing	-2.18 (-114.27, 109.91)	-194.14 (-344.46, -43.82) *	-1.80 (-3.03, -0.57) **
Percent non-Hispanic White	-213.09 (-362.67, -63.52) **	-37.97 (-254.84, 178.90)	0.37 (-1.38, 2.12)
Baseline Sociodemographics *Time:			
Percent below poverty line	37.76 (11.10, 64.41) **	16.06 (7.35, 24.78) **	0.04 (0.00, 0.07) *
Percent of labour force unemployed	1.87 (-24.57, 28.31)	-3.26 (-11.90, 5.39)	0.00 (-0.04, 0.03)
Median household income	11.73 (-7.10, 30.55)	-2.28 (-8.42, 3.85)	0.01 (-0.02, 0.03)
Percent occupied housing	-19.72 (-36.91, -2.53) *	3.32 (-2.30, 8.94)	0.02 (0.00, 0.04)
Percent non-Hispanic White	66.78 (46.73, 86.84) ***	17.26 (10.71, 23.81) ***	0.05 (0.02, 0.07) **
Change in Sociodemographics *Time:			
Percent below poverty line	0.03 (-3.73, 3.79)	-2.00 (-3.14, -0.86) **	0.00 (-0.01, 0.01)
Percent of labour force unemployed	-6.29 (-9.85, -2.72) **	-1.22 (-2.30, -0.15) *	-0.01 (-0.02, 0.00)
Median household income	21.40 (18.60, 24.19) ***	0.26 (-0.58, 1.09)	0.01 (0.00, 0.01) *
Percent occupied housing	-6.11 (-9.45, -2.77) **	-0.15 (-1.16, 0.86)	-0.02 (-0.03, -0.02) ***
Percent non-Hispanic White	3.29 (-0.33, 6.91)	-1.32 (-2.41, -0.24) *	0.00 (0.00, 0.01)

Abbreviations: CI, confidence interval

* <0.05;

** <0.01;

*** <0.0001

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All estimates derived from linear mixed models by infrastructure, adjusted for all sociodemographics, time-invariant (city, land area) and time-varying (population) confounders. Scaled so that estimates represent the mean change for a stand deviation difference.

η in meters

ζ , Percent of neighbourhood streets covered by bus transit service