# Walkability and cardiometabolic risk factors: Cross-sectional and longitudinal associations from the Multi-Ethnic Study of Atherosclerosis

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## ABSTRACT

We used data from 3227 older adults in the Multi-Ethnic Study of Atherosclerosis (2004–2012) to explore cross-sectional and longitudinal associations between walkability and cardiometabolic risk factors. In cross-sectional analyses, linear regression was used to estimate associations of Street Smart Walk Score® with glucose, triglycerides, HDL and LDL cholesterol, systolic and diastolic blood pressure, and waist circumference, while logistic regression was used to estimate associations with odds of metabolic syndrome. Econometric fixed effects models were used to estimate longitudinal associations of changes in walkability with changes in each risk factor among participants who moved residential locations between 2004 and 2012 ($n=583$). Most cross-sectional and longitudinal associations were small and statistically non-significant. We found limited evidence that higher walkability was cross-sectionally associated with lower blood pressure but that increases in walkability were associated with increases in triglycerides and blood pressure over time. Further research over longer time periods is needed to understand the potential for built environment interventions to improve cardiometabolic health.

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## 1. Introduction

Heart disease, stroke, and diabetes are three of the leading causes of death worldwide, resulting in approximately 16.7 million deaths (nearly 30 percent of all global deaths) in 2012 with even greater rates in high-income countries (World Health Organization, 2014). Cardiometabolic risk factors, including elevated lipids, glucose, and hypertension, are projected to continue to rise, especially as the population ages and increasingly in middle- to low-income countries (Smith et al., 2012). Thus, identifying population-level strategies to reduce cardiometabolic risk is a global public health priority.

While individual and pharmaceutical-related interventions play a role in reducing cardiometabolic risk (National Center for Health Statistics, 2011), place-based strategies have the potential to improve population health outcomes on a broader scale. In line with this

notion, a growing body of literature has explored the relationship between the built environment and cardiovascular health. Typically operationalized using measures of density, land use mix, and street connectivity (Saelens et al., 2003), walkable built environments have been found in cross-sectional studies to be positively associated with walking (Van Dyck et al., 2010; Witten et al., 2012; Li et al., 2005) and physical activity (Van Dyck et al., 2010; Witten et al., 2012; Hoehner et al., 2011; Berke et al., 2007; Li et al., 2008; Garden and Jalaludin, 2008; King et al., 2005; Frank et al., 2004) and inversely associated with body mass index (BMI) (Hoehner et al., 2011; Berke et al., 2007; Li et al., 2008; Garden and Jalaludin, 2008; Frank et al., 2004; Joshu et al., 2008; Rundle et al., 2007). More recently, longitudinal evidence has suggested similar associations between the built environment and walking (Hirsch et al., 2014a; Giles-Corti et al., 2013; Gebel et al., 2011; Mumford et al., 2011; Michael et al., 2010), cycling (Beenackers et al., 2012), overall physical activity (Gebel et al., 2011; McAlexander et al., 2011; Calise et al., 2012), and BMI (Hirsch et al., 2014a, 2014b; Berry et al., 2010). These findings, derived from studies in the United States, Canada, Europe, Australia, and New Zealand, suggest that the settings in which people live may influence proximal behaviors that

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in turn influence health.

Physical activity and normal body weight have a variety of cardiometabolic benefits, suggesting that the built environment—through its documented relationships with physical activity and BMI—may also be associated with more distal health outcomes such as glucose, triglycerides, cholesterol, and blood pressure. Regular physical activity can reduce fasting glucose levels, and thus reduce the risk of type 2 diabetes, by facilitating the uptake, transport, and regulation of muscle glucose (Goodyear and Kahn, 1998; Hayes and Kriska, 2008; Sigal et al., 2004; Goodpaster and Brown, 2005). Through its influence on lipid metabolism (Pires et al., 2012), physical activity can lead to improved lipid profiles including lower triglyceride levels (Pires et al., 2012; Green et al., 2014; Gordon-Larsen et al., 2009), greater high-density lipoprotein cholesterol levels (Pires et al., 2012; Donnelly et al., 2000; Murphy et al., 2002), lower total cholesterol levels (Murphy et al., 2002), and lower lipid accumulation (Green et al., 2014). The cardiovascular benefits of physical activity also include improved blood pressure, and past research has found moderate activities such as active commuting (walking or cycling to work) (Gordon-Larsen et al., 2009) and daily walking (Moreau et al., 2001) to be associated with lower diastolic (Gordon-Larsen et al., 2009) and systolic (Moreau et al., 2001) blood pressure. Additionally, the converse of physical activity—sedentary time—is an independent risk factor for adverse cardiometabolic health (Green et al., 2014; Sugiyama et al., 2016). These biological mechanisms suggest potential pathways through which the built environment, as a facilitator of or barrier to physical activity, may influence downstream cardiometabolic risk factors.

Limited research has been conducted to date on the relationship between the built environment and cardiometabolic risk (Leal and Chaix, 2011). Two recent cross-sectional analyses in the United States and Australia found that neighborhood physical activity resources (Auchincloss et al., 2008) and walkability (Müller-Riemenschneider et al., 2013) were associated with lower insulin resistance and lower risk of type 2 diabetes. Baldock et al. (2012) found perceived neighborhood land use mix, aesthetics, and pedestrian infrastructure to be correlated with lower risk of metabolic syndrome among adults in Australia. Two cross-sectional studies in France and the Netherlands found measures of population and housing density (Chaix et al., 2008; Agyemang et al., 2007) and green space quality (Agyemang et al., 2007) to be correlated with lower systolic blood pressure. Mujahid et al. (2008) recorded an association between higher neighborhood walkability and lower prevalence of hypertension among older adults in the United States, although this association was not robust to adjustment for race. A small number of studies in the United States and Australia have analyzed composite cardiometabolic risk measures (Coffee et al., 2013; Dengel et al., 2009), providing some cross-sectional evidence of a positive association between walkable built environments and improved cardiometabolic profiles.

Even fewer studies have examined this relationship longitudinally (Leal and Chaix, 2011). Li et al. (2009) found higher neighborhood walkability to be associated with decreases in systolic and diastolic blood pressure over a one-year period among middle-aged and older adults in Portland, Oregon. Auchincloss et al. (2009) examined the role of healthy food sources and recreational facilities, finding greater availability of both to be associated with lower diabetes incidence over a five-year period among older adults in the United States. Paquet et al. (2014) found the risk of developing pre-diabetes or diabetes to be lower among Australian adults living in areas with larger public open spaces and higher walkability, although no such relationships were observed for the risk of hypertension or dyslipidemia. Sundquist et al. (2015) observed an association between higher walkability and lower incidence of type 2 diabetes over a three-year follow-up period in

Swedish adults, but this relationship did not persist after controlling for individual-level sociodemographic characteristics. Examining older adults in the United States over a 10-year period, Christine et al. (2015) found a lower incidence of type 2 diabetes among those with greater access to healthy food and physical activity resources.

While these longitudinal studies have explored the incidence of cardiometabolic risk factors over time, only Christine et al. (2015) related these changes to time-varying built environment exposures. Thus, there is a critical need for further research on the relationship between *changes* in the built environment and *changes* in cardiometabolic health. Because changes to the built environment often occur over long time frames, one useful research design is to examine changes in health among individuals who move residential locations and are therefore exposed to a new and potentially distinct neighborhood environment. This approach, which has been used in previous studies to examine longitudinal associations of the built environment with physical activity, walking, and BMI (Hirsch et al., 2014a; Giles-Corti et al., 2013; Mumford et al., 2011; Handy et al., 2008; Lee et al., 2009; Wells and Yang, 2008; Christian et al., 2013), has the potential to provide a more thorough understanding of the relationship between the built environment and cardiometabolic health.

Given the emerging nature of this evidence base, there is a need for both cross-sectional and longitudinal research to extend these findings to different populations and contexts. The present study responds to this need by exploring cross-sectional and longitudinal associations between the neighborhood built environment and cardiometabolic risk factors in the Multi-Ethnic Study of Atherosclerosis (MESA). As previous work in this sample has indicated a relationship between changes in the built environment and changes in both walking and obesity (Hirsch et al., 2014a, 2014b, 2014c), this paper considers associations of the neighborhood walking environment with cardiometabolic risk factors potentially affected by physical activity and body weight. The longitudinal portion of the study focuses on respondents who move residential locations in order to assess changes in both environment and health. Through this multifaceted approach, we contribute to an enhanced understanding of the potential connections between modifications that planners and policy makers can make to the built environment and a wider set of health outcomes.

## 2. Methods

### 2.1. Sample

The sample for this analysis was from MESA, a longitudinal study with racially and ethnically diverse participants recruited from six regions across the United States (Forsyth County, North Carolina; New York, New York; Baltimore, Maryland; St. Paul, Minnesota; Chicago, Illinois; Los Angeles, California) beginning in 2000. MESA respondents are a population-based sample of 6814 men and women who were 45–84 years of age and had no history of clinical cardiovascular disease at baseline (Bild et al., 2002).

This analysis used data from exam 3 (January 2004–September 2005) and exam 5 (April 2010–February 2012). The cross-sectional sample consisted of respondents who participated in the Neighborhood Ancillary Study and gave complete information on all variables of interest at exam 5. Respondents with diabetes mellitus (DM) at exam 5 were also excluded from the cross-sectional analysis given the focus on metabolic syndrome, the interpretation of which is not as meaningful in the presence of DM. Among the 4622 individuals who completed exam 5, 621 were excluded for missing data and an additional 774 were excluded for having DM,

leaving a final cross-sectional sample of $n=3227$. Compared to those excluded from the cross-sectional analysis due to missing data, the final cross-sectional sample had higher average incomes, educational attainment, and neighborhood socioeconomic status; lower average systolic blood pressure, glucose, triglycerides, and waist circumference; a higher proportion of white and employed respondents; and a lower proportion of respondents with metabolic syndrome (data not shown).

The longitudinal sample consisted of respondents who participated in the Neighborhood Ancillary Study, moved residential locations between exams 3 and 5, provided complete information on all variables of interest at both exams, and were free of DM at baseline (exam 3). Among the 4565 individuals who participated in both exams, 3646 were excluded because they did not move, an additional 240 were excluded due to missing data, and an additional 96 were excluded for having DM, leaving a final longitudinal sample of $n=583$. Compared to those excluded from the longitudinal analysis due to missing data, the final longitudinal sample had higher educational attainment and baseline neighborhood walkability; higher average incomes and neighborhood socioeconomic status at both baseline and follow-up; lower average systolic blood pressure and glucose at both baseline and follow-up; lower triglycerides and waist circumference at baseline; a higher proportion of employed (baseline and follow-up) and white respondents; and a lower proportion of respondents with metabolic syndrome at both baseline and follow-up (data not shown).

The study was approved by Institutional Review Boards (IRBs) at each clinic site. Participants provided written informed consent before being enrolled into MESA. Separate IRB approval was also obtained for the analyses conducted in the present paper.

## 2.2. Exposure variable

The built environment in proximity to each respondent's residential location was measured using Street Smart Walk Score® (Front Seat Management, LLC, www.walkscore.com). This score is based on an algorithm that assigns a value from 0 to 100 to locations; higher values reflect greater walkability. The score is calculated based on proximity along walking routes to various types of amenities (e.g. shopping, restaurants, entertainment, schools, parks, libraries, fitness centers), as well as the mix of these amenities. To further account for pedestrian friendliness, the algorithm is adjusted for two measures of street connectivity: intersection density and average block length (Front Seat Management, LLC, 2014). Compared to the traditional Walk Score®, Street Smart Walk Score® offers a more complete measure of walkability by incorporating distance to amenities along pedestrian-friendly streets, rather than relying on straight-line distances.

In previous studies, the traditional Walk Score® algorithm has been shown to be a valid indicator of neighborhood walkability. Duncan et al. (2011) found Walk Score® to be strongly correlated with objective measures of population density, retail density, and street connectivity in four geographically diverse metropolitan areas across the United States (Spearman correlations: 0.64–0.80), while two studies in Rhode Island observed strong correlations between Walk Score® and the objectively-measured density of intersections, streets, residences, and amenities (Pearson correlations: 0.74–0.81) (Carr et al., 2010, 2011). Although Street Smart Walk Score® has not been assessed in this way, it is likely to be a more valid measure of walkability than the traditional Walk Score® due to its incorporation of walking routes and street connectivity measures. Furthermore, past research has found Street Smart Walk Score® to be associated with walking behavior (Hirsch et al., 2014a; Hirsch et al., 2013), providing evidence of its predictive validity.

As historical data were not available, Street Smart Walk Scores® from May 2012 were used for both exams. Thus, for respondents in the longitudinal sample (i.e. movers), changes in exposure to the built environment stem only from changes in their residential location between the two exam periods.

## 2.3. Outcome variables

The cardiometabolic risk factors considered in this analysis included metabolic syndrome, its individual components (fasting glucose, triglycerides, high-density lipoprotein (HDL) cholesterol, systolic and diastolic blood pressure, waist circumference), and low-density lipoprotein (LDL) cholesterol. Continuous measures of glucose, triglycerides, and cholesterol were obtained from a fasting blood sample collected during the clinical examination. Blood pressure was measured after five minutes of rest in the seated position; the average of the second and third readings was used. Waist circumference was measured to the nearest 0.1 cm using a steel measuring tape. Based on the distribution of observed data, log transformations of glucose, triglycerides, and HDL cholesterol were used in the final regressions.

Metabolic syndrome was measured as a dichotomous variable indicating whether participants exhibited three or more of the following risk factors: waist circumference $\geq 102$ cm for men or $\geq 88$ cm for women; triglycerides $\geq 150$ mg/dL; HDL cholesterol $\leq 40$ mg/dL for men or $\leq 50$ mg/dL for women; blood pressure $\geq 130/85$ mmHg or reported use of hypertension medication; fasting glucose $\geq 100$ mg/dL (NHLBI/AHA, 2004).

## 2.4. Covariates

Covariates were identified for inclusion based on *a priori* knowledge and a Directed Acyclic Graph (DAG) to find the minimally sufficient adjustment set. Information from an interviewer-administered questionnaire was used to measure individual sociodemographic characteristics (age, gender, race/ethnicity, education, household income, employment status, marital status) that may influence both residential location (exposure to the home neighborhood built environment) and cardiometabolic health. Race/ethnicity categories included non-Hispanic White, non-Hispanic Chinese, non-Hispanic Black, and Hispanic. Self-reported information on highest degree obtained was used to classify participants into three education categories: high school/GED or less, some college or technical school, and bachelor's degree or higher. Respondents reported their combined household income as falling into one of 13 categories ( < $5000, $5000–7999, $8000–11,999, $12,000–15,999, $16,000–19,999, $20,000–24,999, $25,000–29,999, $30,000–34,999, $35,000–39,999, $40,000–49,999, $50,000–74,999, $75,000–99,999, $\geq$ $100,000), and a measure in U.S. dollars was created as the mid-point of the selected category. Participants were considered employed if they reported working at least part-time. Marital status included "currently married or living with a partner," with those not married consisting of participants who were widowed, divorced, separated, or never married. Use of hypertension, lipid, and statins medications was assessed from self-reported data. Information from medical records and in-person interviews was used to determine whether participants had experienced any cardiovascular events and to create a dichotomous measure of cardiovascular disease (1 if one or more cardiovascular events had occurred prior to the exam date, 0 otherwise).

Additionally, a neighborhood socioeconomic status (SES) index was included to account for contextual influences of the neighborhood social environment. This index was created from U.S. Census and American Community Survey (ACS) data at the census tract level (U.S. Census 2000 for exam 3 participants interviewed in 2004, ACS 2005–2009 for exam 3 participants interviewed in

2005, and ACS 2007–2011 for all exam 5 participants). Using principal component analysis, five factors were derived from 21 tract-level measures of race/ethnicity, prevalence of foreign-born residents, crowding, educational attainment, occupation, income, wealth, poverty, employment status, and housing characteristics. Higher index values indicate lower neighborhood SES (i.e. greater neighborhood deprivation) (Christine et al., 2015).

## 2.5. Statistical analyses

Statistical analyses were conducted in 2014 and 2015 using Stata version 13.0. Descriptive statistics were used to assess sample characteristics, compare movers and non-movers, and compare selected characteristics of movers across tertiles of the change in Street Smart Walk Score® resulting from residential relocation. The $\chi^2$ test, Fisher's exact test, and analysis of variance were used as appropriate to test for statistically significant differences.

For the cross-sectional analysis, linear regression (for glucose, triglycerides, HDL and LDL cholesterol, systolic and diastolic blood pressure, and waist circumference) and logistic regression (for odds of metabolic syndrome) were used to estimate the associations of walkability with each cardiometabolic risk factor for the full sample at exam 5 ($n=3227$). Each outcome was modeled as a function of Street Smart Walk Score®, study site, and the individual- and neighborhood-level sociodemographic covariates.

For the longitudinal analysis, econometric fixed effects models (Allison, 2005) were used to estimate the relationship between within-person change in Street Smart Walk Score® and within-person change in each cardiometabolic risk factor among respondents who moved residential locations between exams 3 and 5 ($n=583$). Econometric fixed effects models treat each individual as his or her own control, basing coefficient estimates on individual changes in exposure, outcome, and covariates over time. The unit of analysis for these models was thus the individual respondent observed at two time points (exams 3 and 5). Within-person change in each cardiometabolic outcome between exams 3 and 5 was modeled as a function of within-person change in Street Smart Walk Score®, adjusting for within-person change in each time-varying covariate (household income, employment status, marital status, and neighborhood SES). Because econometric fixed effects models are based on within-person change, they control for all observed and unobserved characteristics that remain constant over time. This means that time-invariant observed covariates (baseline age, gender, race/ethnicity, and educational attainment) were not directly specified in the fixed effects models. However, interactions between each of these covariates and time were included in the models to account for the possibility that the effects of these characteristics on health vary over time.

In both the cross-sectional and longitudinal analyses, we estimated additional regression models to account for the fact that some participants were taking medications (hypertension, lipid, and statins medications) that may have affected the outcomes of interest. Adjusting for medication use with a binary covariate would be inappropriate because medication use is an outcome of poor cardiometabolic health (Tobin et al., 2005). Instead, we used a non-parametric method to "correct" the observed values of triglycerides, LDL cholesterol, and systolic and diastolic blood pressure for individuals who reported taking medications related to these health outcomes (lipid and statins medications for triglycerides and LDL cholesterol, hypertension medications for systolic and diastolic blood pressure). This method treated the "true" value as censored, or missing, for individuals taking medications and attempted to approximate the underlying value that would have been observed in the absence of medication use. For each

outcome, individuals taking a relevant medication were ranked from lowest to highest according to their observed outcome values, and a corrected value was assigned to each individual as the mean observed value for all those who were ranked higher. The regression models were then re-estimated with these corrected values for participants taking medications and the original (i.e. uncorrected) values for participants who did not report medication use. This method was not conducted for glucose because those with DM were excluded, and it was not conducted for HDL cholesterol or metabolic syndrome due to the lack of medications specifically targeting these outcomes.

Sensitivity analyses were conducted to account for cardiovascular disease (in cross-sectional and longitudinal regressions) and time since moving (in longitudinal regressions only). In the first of these analyses, a binary indicator of cardiovascular disease was included as a covariate in the regression models. In the second sensitivity analysis, Street Smart Walk Score® was interacted with time since moving (in months) to test whether the relationship between walkability and cardiometabolic health was moderated by time in the new residential environment. This approach accounted for the possibility that changes in health behavior and downstream cardiometabolic risk factors may take time to appear, potentially leading to stronger environment–health relationships among those who have lived in their new neighborhoods for a longer period of time.

## 3. Results

### 3.1. Descriptive statistics

For the cross-sectional sample ($n=3227$), participants' age at exam 5 ranged from 53 to 94 with a mean of 69.37 (standard deviation (SD)=9.46) (Table 1). Street Smart Walk Score® values at participants' exam 5 residential locations ranged from 0 to 100 with a mean of 54.32 (SD=32.44). Twenty percent of participants lived in areas classified as "walker's paradise" (Street Smart Walk Score® of 90–100, daily errands do not require a car), while just over 40 percent lived in areas classified as "car-dependent" (Street Smart Walk Score® of 0–49, most or almost all errands require a car) (Front Seat Management, LLC, 2015). On average, participants were within normal ranges for fasting glucose, triglycerides, HDL cholesterol, and diastolic blood pressure, but slightly above the optimal levels of LDL cholesterol, systolic blood pressure, and waist circumference (NIH National Cholesterol Education Program 2001). Approximately one-quarter of respondents (26.56 percent) were classified as having metabolic syndrome.

For participants who moved between exams 3 and 5 ($n=583$), the change in walkability accompanying residential relocation ranged from 99 points lower to 93 points higher, with the average participant moving to an area with 7.33 points lower walkability (SD=32.15). In their new residential locations, 14 percent of participants lived in areas classified as "walker's paradise" and 47 percent lived in areas classified as "car-dependent" (compared to 18 percent and 36 percent, respectively, prior to moving). The sample of movers on average experienced a decrease in income, employment rate, and marriage rate. While increases in fasting glucose, systolic blood pressure, waist circumference, and metabolic syndrome classification were observed, the time between exams was marked by an average improvement in triglycerides, LDL and HDL cholesterol, and diastolic blood pressure among movers.

Compared with non-movers who participated in both exams, movers were younger; had lower incomes, higher initial triglyceride levels, and lower initial HDL cholesterol levels; were more likely to be Chinese or Hispanic and to be employed; and were less

**Table 1**
Descriptive statistics for full sample (*n*=3227) at exam 5 and for movers only (*n*=583) at exams 3 and 5, Multi-Ethnic Study of Atherosclerosis.

| Characteristics | Full sample at exam 5 (*n*=3227) | Movers between exams 3 and 5 (*n*=583) | |
| --- | --- | --- | --- |
| | Exam 5<br>Mean (SD) or % | Exam 3<br>Mean (SD) or % | Exam 5<br>Mean (SD) or % |
| ***Cardiometabolic risk factors*** | | | |
| Fasting glucose, mg/dL | 94.17 (9.76) | 90.87 (9.59) | 96.88 (16.29) |
| Triglycerides, mg/dL | 104.85 (52.16) | 125.80 (68.66) | 110.73 (56.52) |
| LDL cholesterol, mg/dL | 108.38 (31.01) | 113.62 (30.45) | 108.86 (31.77) |
| HDL cholesterol, mg/dL | 57.28 (17.08) | 51.06 (15.02) | 54.54 (16.16) |
| Systolic blood pressure, mmHg | 122.60 (20.15) | 118.56 (18.67) | 121.55 (20.42) |
| Diastolic blood pressure, mmHg | 68.42 (9.90) | 69.72 (9.97) | 69.11 (10.58) |
| Waist circumference, cm | 97.55 (14.14) | 96.25 (13.86) | 98.35 (14.18) |
| Metabolic syndrome (%)[a] | 26.56 | 26.93 | 31.22 |
| ***Built environment exposure*** | | | |
| Street Smart Walk Score® | 54.32 (32.44) | 57.23 (30.60) | 49.90 (31.55) |
| Car-dependent 1 (0–24) | 24.67 | 19.04 | 26.59 |
| Car-dependent 2 (25–49) | 16.86 | 16.81 | 20.24 |
| Somewhat walkable (50–69) | 20.24 | 25.90 | 21.10 |
| Very walkable (70–89) | 18.59 | 19.90 | 18.35 |
| Walker's paradise (90–100) | 19.65 | 18.35 | 13.72 |
| ***Sociodemographic covariates*** | | | |
| Age, in years | 69.37 (9.46) | 61.39 (9.22) | 67.69 (9.20) |
| Female (%) | 53.58 | 52.32 | –[b] |
| Race/ethnicity (%) | | | |
| White, Caucasian | 45.65 | 39.45 | –[b] |
| Chinese American | 11.96 | 17.15 | –[b] |
| Black, African American | 23.40 | 22.47 | –[b] |
| Hispanic | 19.00 | 20.93 | –[b] |
| Education (%) | | | |
| High school/GED or less | 27.92 | 27.44 | –[b] |
| Some college, technical | 28.57 | 29.16 | –[b] |
| Bachelor's or higher | 43.51 | 43.40 | –[b] |
| Household income, in thousands | 56.88 (35.93) | 52.25 (35.58) | 50.84 (35.80) |
| Currently employed (%) | 46.02 | 62.78 | 47.34 |
| Currently married (%) | 60.40 | 59.35 | 55.06 |
| Neighborhood SES index[c] | − 0.62 (1.26) | − 0.51 (1.36) | − 0.53 (1.13) |

SD=standard deviation, LDL=low-density lipoprotein, HDL=high-density lipoprotein, GED=general equivalency diploma, SES=socioeconomic status.

[a] Metabolic syndrome was measured as a dichotomous variable indicating whether participants exhibited three or more of the following risk factors: waist circumference $\geq$ 102 cm for men or $\geq$ 88 cm for women; triglycerides $\geq$ 150 mg/dL; HDL cholesterol $\leq$ 40 mg/dL for men or $\leq$ 50 mg/dL for women; blood pressure $\geq$ 130/85 mmHg or reported use of hypertension medication; fasting glucose $\geq$ 100 mg/dL (NHLBI/AHA, 2004).

[b] These characteristics are considered to be time-invariant and thus have the same values for both exams.

[c] Higher values indicate lower neighborhood socioeconomic status (i.e. greater neighborhood deprivation).

likely to be married (data not shown). No significant differences between movers and non-movers were observed for gender, educational attainment, initial Street Smart Walk Score®, or initial levels of fasting glucose, LDL cholesterol, metabolic syndrome, blood pressure, or waist circumference (data not shown).

### 3.2. Cross-sectional analyses

The cross-sectional associations between Street Smart Walk Score® and all measured cardiometabolic risk factors were small in magnitude and statistically non-significant (Table 2). After accounting for medication use, higher Street Smart Walk Score® was associated with lower diastolic blood pressure (Table 2). Sensitivity analyses adjusting for cardiovascular disease diagnosis produced results of similar magnitude, direction, and statistical significance (data not shown).

### 3.3. Longitudinal analyses

Descriptive statistics for selected baseline and change variables showed few significant differences across tertiles of change in Street Smart Walk Score® (Table 3). Individuals experiencing the largest increase in walkability had higher initial fasting glucose levels, while individuals experiencing the largest decrease in walkability were more likely to be employed at baseline.

Individuals experiencing the largest increase in walkability had the lowest average baseline (pre-move) neighborhood SES but moved to areas with higher SES; individuals experiencing the largest decrease in walkability, on the other hand, moved to areas with lower neighborhood SES. Thus, changes in walkability were positively associated with changes in neighborhood SES (i.e. moving to a more walkable neighborhood was associated with moving to a higher-SES neighborhood, and vice versa).

The longitudinal associations between Street Smart Walk Score® and all measured cardiometabolic risk factors were small in magnitude and statistically non-significant (Table 4). After accounting for medication use, changes in walkability were associated with changes in triglycerides and systolic blood pressure in the unexpected (positive) direction (Table 4). Sensitivity analyses adjusting for cardiovascular disease diagnosis produced similar results (data not shown). Interactions between Street Smart Walk Score® and time since residential relocation were non-significant and also produced similar results (data not shown), suggesting that the relationship between walkability and health was not moderated by length of time in the new residence.

### 4. Discussion

We did not find consistent evidence of cross-sectional or longitudinal associations between neighborhood walkability and

**Table 2**
Mean differences and odds ratios for cardiometabolic risk factors associated with a 10-point higher Street Smart Walk Score® at exam 5, Multi-Ethnic Study of Atherosclerosis.

| Cardiometabolic risk factors | Cross-sectional sample at exam 5 (*n*=3227)[a] | | Accounting for medication use[d] | |
|---|---|---|---|---|
| | Coefficient (SE) | p-value | Coefficient (SE) | p-value |
| Fasting glucose, mg/dL[b] | 0.9994 (0.0008) | 0.44 | – | – |
| Triglycerides, mg/dL[b,e] | 1.0043 (0.0034) | 0.21 | 1.0021 (0.0035) | 0.54 |
| LDL cholesterol, mg/dL[e] | 0.1004 (0.2352) | 0.67 | 0.0276 (0.2115) | 0.90 |
| HDL cholesterol, mg/dL[b] | 0.9982 (0.0020) | 0.35 | – | – |
| Systolic blood pressure, mmHg | − 0.1824 (0.1504) | 0.23 | − 0.2944 (0.1582) | 0.06 |
| Diastolic blood pressure, mmHg | − 0.1029 (0.0730) | 0.16 | − 0.1476 (0.0701) | **0.04** |
| Waist circumference, cm | − 0.0381 (0.1048) | 0.72 | – | – |
| Metabolic syndrome (OR)[c] | 1.0022 (0.0185) | 0.91 | – | – |

SE=standard error, LDL=low-density lipoprotein, HDL=high density lipoprotein, OR=odds ratio.
**Boldface** indicates statistical significance ($p < 0.05$).

[a] Adjusted for baseline study site and selected sociodemographic covariates (age, gender, race/ethnicity, educational attainment, household income, employment status, marital status, neighborhood socioeconomic status index).

[b] Reported values for fasting glucose, triglycerides, and HDL cholesterol are percentage differences (i.e. exponentiated values of the original coefficients), as these dependent variables were logged for the regression analysis.

[c] Reported coefficient for metabolic syndrome is an odds ratio, as this dependent variable is dichotomous.

[d] Non-parametric methods were used to correct values for individuals who reported taking relevant medications (lipid and statins medications for triglycerides and LDL cholesterol, hypertension medications for systolic and diastolic blood pressure) (Methods described in Section 2.5).

[e] Non-parametric correction was conducted separately for lipid and statins medications; results were similar, and those for statins use are presented.

cardiometabolic risk factors among a geographically and ethnically diverse sample of older adults. These results may suggest that relationships previously observed in this sample between Street Smart Walk Score® and walking and BMI (Hirsch et al., 2014a) were insufficient to generate notable gains in cardiometabolic health over the same time period. There was an inverse cross-sectional association between walkability and diastolic blood pressure, but only after accounting for medication use. This could indicate that participants in more walkable neighborhoods were more likely to use hypertension medications, and failing to account for this relationship biased the estimated associations toward the null. In longitudinal analyses, however, increases in walkability were associated with increases in triglycerides and systolic blood pressure, but only after accounting for medication use. This could suggest that individuals who moved to more walkable neighborhoods in this sample were less likely to use statins and hypertension medications, resulting in downward bias (i.e. toward null) when medication use was not accounted for.

The limited magnitude of relationships in this study may reflect the long causal chain potentially linking the built environment to cardiometabolic health. While walkability may influence proximal behaviors such as walking, the cardiometabolic outcomes considered in this analysis are more distal and are thus likely to be influenced by a variety of intervening factors (including diet and genetic predisposition) operating over longer time periods. Other research has similarly found the neighborhood food environment to be associated with obesity prevalence but not with more distal outcomes such as diabetes, cholesterol, and hypertension (Morland et al., 2006).

The findings may also be attributable to the analytic sample,

which consisted of older adults whose cardiometabolic profiles may be more firmly set and less amenable to change than those of younger populations. Further work is needed to analyze this relationship among a broader and more representative cohort.

Furthermore, the results may be affected by unmeasured confounding related to economic trends and the stress of moving. While the reduction in income and employment status among movers between exams 3 and 5 could reflect retirement, it could also be indicative of the recession that occurred during this time period. If individuals who moved to more walkable neighborhoods did so in order to downsize, to transition into public or subsidized housing, or to move in with family members, the estimated associations may be confounded by (possibly) countervailing influences of economic changes on cardiometabolic risk factors. While this analysis controlled for changes in household income and neighborhood SES, and while increases in walkability after moving were associated with increases in neighborhood SES, it is possible that economic shifts manifested themselves in unmeasured ways. Additionally, as moving is often a stressful life event that can affect cardiometabolic health through many pathways, this study's longitudinal focus on movers may make it difficult to disentangle the influence of the built environment.

Several additional considerations may be relevant to the longitudinal analysis. First, fixed effects models estimate contemporaneous and relatively short-term associations between changes in exposure and changes in outcome. It is plausible that the translation of changes in walking and BMI into better overall cardiometabolic health occurs over much longer periods and hence may not be detectable with the analytical approach used in this study. Next, the statistical power of the longitudinal analysis was limited by the relatively small sample of movers and the use of econometric fixed effects models, which rely exclusively on within-unit variation. Finally, while previous work has found a longitudinal relationship between walkability and transportation-related walking in this cohort (Hirsch et al., 2014a), it is possible that transportation-related walking does not constitute a sufficient proportion of overall physical activity to change cardiometabolic health over the short time period examined in this study.

To the extent that attitudes and preferences toward neighborhood attributes and health behaviors remained stable between exams 3 and 5, the use of fixed effects models—which control for all observed and unobserved time-invariant characteristics whose effects remain constant over time (Allison, 2005; Lovasi and Goldsmith, 2014)—offered a way to address residential self-selection. However, a focus on residential relocation has important limitations, including the inability to describe the pathways through which neighborhood changes may affect individual cardiometabolic outcomes (Lovasi and Goldsmith, 2014).

Additionally, although a variety of time-varying controls were included, the possibility of confounding by unobserved time-varying characteristics cannot be ruled out. Data on reasons for moving, which could be relevant for understanding residential self-selection, were not available. This is particularly important because individual attitudes and preferences toward the environment and health may in fact change over time, and potentially in response to new environmental settings. In this case, the fixed effects estimates in this study may be confounded by unobserved, time-varying attitudes and preferences. Next, the use of Street Smart Walk Score® data from a single point in time required the assumption that the built environment remained stable between exams 3 and 5; because changes to the built environment tend to occur slowly and incrementally, however, this assumption was likely appropriate. Finally, due to sample size limitations, the potential for differences across study sites and effect modification by initial Street Smart Walk Score® levels could not be assessed.

## 5. Conclusions

This study examined cross-sectional and longitudinal relationships between walkability and cardiometabolic health among a sample 53–94 years of age, finding limited evidence of associations with a range of cardiometabolic risk factors. While recent cross-sectional and longitudinal evidence suggests that neighborhood walkability is associated with higher physical activity levels and lower BMI (Hirsch et al., 2014a; Van Dyck et al., 2010; Witten et al., 2012; Li et al., 2005; Hoehner et al., 2011; Berke et al., 2007; Li et al., 2008; Garden and Jalaludin, 2008; King et al., 2005; Frank et al., 2004; Joshu et al., 2008; Rundle et al., 2007; Giles-Corti et al., 2013; Gebel et al., 2011; Mumford et al., 2011; Michael et al., 2010; Beenackers et al., 2012; McAlexander et al., 2011; Calise et al., 2012; Hirsch et al., 2014b; Berry et al., 2010), it remains uncertain whether these benefits translate into

**Table 3**
Descriptive statistics by tertile of change in Street Smart Walk Score® between exams 3 and 5 among movers (*n*=583), Multi-Ethnic Study of Atherosclerosis.

| Characteristics | Groups by change in Street Smart Walk Score® | | | |
| --- | --- | --- | --- | --- |
| | *Decrease (change ≤ − 15), n=207*[a] | *Minimal (change > − 15 and ≤ 2), n=192*[a] | *Increase (change > 2), n=184*[a] | *p*[b] |
| ***Cardiometabolic risk factors at exam 3*** | | | | |
| Fasting glucose, mg/dL | 90.12 (9.59) | 90.14 (8.70) | 92.47 (10.32) | **0.02** |
| Triglycerides, mg/dL | 128.35 (71.12) | 122.38 (65.52) | 126.51 (69.26) | 0.68 |
| LDL cholesterol, mg/dL | 114.26 (29.56) | 113.74 (32.43) | 112.77 (29.41) | 0.89 |
| HDL cholesterol, mg/dL | 51.40 (13.95) | 50.56 (16.95) | 51.21 (14.09) | 0.85 |
| Systolic blood pressure, mmHg | 119.53 (19.95) | 116.62 (17.02) | 119.50 (18.77) | 0.21 |
| Diastolic blood pressure, mmHg | 70.81 (10.45) | 68.88 (9.55) | 69.37 (9.81) | 0.13 |
| Waist circumference, cm | 96.37 (14.19) | 95.57 (13.70) | 96.83 (13.69) | 0.67 |
| Metabolic syndrome (%) | 25.60 | 26.04 | 29.35 | 0.67 |
| ***Change in cardiometabolic risk factors*** | | | | |
| Change in fasting glucose | 5.64 (10.60) | 6.02 (10.83) | 6.41 (18.10) | 0.85 |
| Change in triglycerides | − 21.53 (56.59) | − 10.13 (60.55) | − 12.97 (58.14) | 0.13 |
| Change in LDL cholesterol | − 2.37 (28.95) | − 4.60 (30.78) | − 7.61 (31.86) | 0.24 |
| Change in HDL cholesterol | 3.82 (8.33) | 4.05 (10.93) | 2.51 (9.45) | 0.24 |
| Change in systolic blood pressure | 0.50 (21.25) | 5.24 (20.30) | 3.42 (20.90) | 0.07 |
| Change in diastolic blood pressure | − 1.52 (9.20) | 0.45 (9.86) | − 0.69 (9.67) | 0.12 |
| Change in waist circumference | 2.14 (7.16) | 2.07 (7.98) | 2.07 (8.20) | 0.99 |
| Change in metabolic syndrome (%) | | | | 0.82 |
| New case | 14.98 | 10.94 | 12.50 | |
| Removed case | 8.70 | 8.33 | 8.70 | |
| ***Built environment exposure*** | | | | |
| Street Smart Walk Score® at exam 3 | 67.71 (22.82) | 64.04 (31.58) | 38.35 (28.64) | **0.00** |
| Change in Street Smart Walk Score® | − 39.84 (21.98) | − 3.92 (5.28) | 25.67 (20.30) | –[c] |
| ***Covariates at baseline*** | | | | |
| Age, in years | 60.50 (9.43) | 61.57 (8.86) | 62.19 (9.31) | 0.18 |
| Female (%) | 56.04 | 47.40 | 53.26 | 0.21 |
| Race/ethnicity (%) | | | | 0.59 |
| White, Caucasian | 39.13 | 41.15 | 38.04 | |
| Chinese American | 17.87 | 16.15 | 17.39 | |
| Black, African American | 25.60 | 18.75 | 22.83 | |
| Hispanic | 17.39 | 23.96 | 21.74 | |
| Education (%) | | | | 0.67 |
| High school/GED or less | 23.67 | 29.17 | 29.89 | |
| Some college, technical | 30.92 | 28.12 | 28.26 | |
| Bachelor's or higher | 45.41 | 42.71 | 41.85 | |
| Household income, in thousands | 56.08 (35.56) | 52.50 (36.45) | 47.68 (34.34) | 0.07 |
| Currently employed (%) | 69.57 | 56.25 | 61.96 | **0.02** |
| Currently married (%) | 63.77 | 57.81 | 55.98 | 0.26 |
| Neighborhood SES index[d] | − 0.51 (1.41) | − 0.69 (1.46) | − 0.31 (1.15) | **0.02** |
| ***Change in covariates, as applicable*** | | | | |
| Change in household income | − 0.70 (23.98) | − 1.68 (25.82) | − 1.93 (22.32) | 0.87 |
| Change in employment status (%) | | | | 0.15 |
| Started working | 2.90 | 4.69 | 2.17 | |
| Stopped working | 20.77 | 13.54 | 21.74 | |
| Change in marital status (%) | | | | 0.50 |
| New marriage | 4.83 | 5.73 | 6.52 | |
| No longer married | 7.25 | 11.46 | 11.41 | |
| Change in neighborhood SES | 0.14 (1.30) | 0.03 (1.00) | − 0.27 (1.21) | **0.00** |

LDL=low-density lipoprotein, HDL=high-density lipoprotein, GED=general equivalency diploma, SES=socioeconomic status.
**Boldface** indicates statistical significance (*p* < 0.05).

[a] Tertile 1 (Decrease) defined as change in Street Smart Walk Score® (SSWS) ≤ − 15; Tertile 2 (Minimal Change) defined as change in SSWS > − 15 and ≤ 3; Tertile 3 (Increase) defined as change in SSWS > 3.

[b] *p*-value from $\chi^2$ test or Fisher's exact test as appropriate for categorical variables, and from ANOVA for continuous variables, across tertiles of change in walkability.

[c] *p*-value not computed because this variable was used to determine tertiles.

[d] Higher values indicate lower neighborhood socioeconomic status (i.e. greater neighborhood deprivation).

**Table 4**
Within-person change in cardiometabolic risk factors associated with a 10-unit increase in Street Smart Walk Score® between exams 3 and 5 among movers ($n=583$), Multi-Ethnic Study of Atherosclerosis.

| Cardiometabolic risk factors | Covariate-adjusted associations[a] | | Accounting for medication use[d] | |
|---|---|---|---|---|
| | Coefficient (SE) | p-value | Coefficient (SE) | p-value |
| Fasting glucose, mg/dL[b] | 0.9991 (0.0015) | 0.53 | – | – |
| Triglycerides, mg/dL[b,e] | 1.0062 (0.0053) | 0.25 | 1.0131 (0.0055) | **0.02** |
| LDL cholesterol, mg/dL[e] | −0.1866 (0.3950) | 0.64 | 0.1619 (0.3156) | 0.61 |
| HDL cholesterol, mg/dL[b] | 0.9996 (0.0023) | 0.85 | – | – |
| Systolic blood pressure, mmHg | 0.4220 (0.2736) | 0.12 | 0.4894 (0.2408) | **0.04** |
| Diastolic blood pressure, mmHg | 0.1261 (0.1252) | 0.31 | 0.1805 (0.1058) | 0.09 |
| Waist circumference, cm | 0.0621 (0.1007) | 0.54 | – | – |
| Metabolic syndrome (OR)[c] | 0.9885 (0.0583) | 0.85 | – | – |

SE=standard error, LDL=low-density lipoprotein, HDL=high density lipoprotein, OR=odds ratio.
**Boldface** indicates statistical significance ($p < 0.05$).

[a] Adjusted for time (number of days since last exam), time-varying socio-demographic covariates (household income, employment status, marital status, neighborhood socioeconomic status index), and interactions between time and time-invariant covariates (baseline age, gender, race/ethnicity, educational attainment).

[b] Reported values for fasting glucose, triglycerides, and HDL cholesterol are percentage differences (i.e. exponentiated values of the original coefficients), as these dependent variables were logged for the regression analysis.

[c] Reported coefficient for metabolic syndrome is an odds ratio, as this dependent variable is dichotomous.

[d] Non-parametric methods were used to correct values for individuals who reported taking relevant medications (lipid and statins medications for triglycerides and LDL cholesterol, hypertension medications for systolic and diastolic blood pressure) (Methods described in Section 2.5).

[e] Non-parametric correction was conducted separately for lipid and statins medications; results were similar, and those for statins use are presented

short-term changes in cardiometabolic risk. Further longitudinal research over longer time periods and among a broader range of study populations is needed to more fully understand the potential for place-based built environment interventions to reduce cardiometabolic risk and thereby improve population-level cardiovascular health.

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