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Neighborhood Walkable Urban Form and C-Reactive Protein

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Abstract

Background—Walkable urban form predicts physical activity and lower body mass index, which lower C-reactive protein (CRP). However, urban form is also related to pollution, noise, social and health behavior, crowding, and other stressors, which may complement or contravene walkability effects.

Purpose—This paper assesses within-neighborhood correlation of CRP, and whether three features of walkable urban form (residential density, street connectivity, and land use mix) are associated with CRP levels.

Methods—CRP measures (n=610) and sociodemographic data come from the 2001–3 Chicago Community Adult Health Study, linked with objective built environment data.

Results—Within-neighborhood correlations of CRP are greater than those of related health measures. A one standard deviation increase in residential density predicts significantly higher log CRP (e.g. β=0.11, p<.01) in Chicago, while a one standard deviation increase in land use mix predicts significantly lower CRP (e.g. β=−0. 19, p<0.01). Street connectivity is unrelated to CRP in this highly walkable city.

Discussion—Results suggest residential density may be a risk factor for inflammation, while greater walkability of mixed land use areas may be protective. It may be that negative aspects of density overcome the inflammatory benefits of walking.

Keywords

inflammation; C-reactive protein; walkability; walkable urban form; density; land use mix

Introduction

Contemporary urban environments play a role in the etiology of health and health disparities through a variety of pathways. Considerable research documents neighborhood variation in disease prevalence (Robert, 1999) and how neighborhood conditions may contribute to social disparities in health (Diez Roux, 2012; Williams and Collins, 2001). Identifying and evaluating underlying mechanisms, then, is crucial (Diez Roux and Mair, 2010). Recently, researchers have emphasized the importance of considering a broad range of contextual predictors rather than continuing to focus primarily on socioeconomic conditions (Entwisle,

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2007) and correlated health behaviors. Following this research agenda, the goal is to move beyond documenting social disparities by identifying features of communities which are both causally linked to health outcomes and which can be changed by policymakers, institutions, and residents – and the built environment may fit the bill (Browning et al., 2011).

This paper examines whether residential walkable urban form predicts concentrations of C-reactive protein (CRP), a biomarker of inflammation. The analysis finds that neighborhood variation in CRP by may be greater than that of other conditions commonly studied in neighborhood context. CRP is a plasma protein produced during the nonspecific acute-phase response to inflammation, infection, and tissue damage. CRP levels predict future cardiovascular incidents and disease (Pepys and Hirschfeld, 2003; Sesso et al., 2003) and incident type 2 diabetes (Capuzzi and Freeman, 2007). A meta-analysis of mortality (Emerging Risk Factors Collaboration, 2010) found a one SD increase in log CRP predicted 37% increase in coronary heart disease, 27% for ischemic stroke, and 55% for vascular mortality. Whether CRP has a causal effect, making it an appropriate target for treatment, remains less clear (Paffen and deMaat, 2006).

Prior research examines how race/ethnic, gender, and socioeconomic disparities in CRP may generate health risks for disadvantaged groups (Gruenwald et al., 2009; Koster et al., 2006; O'Reilly et al., 2006). A review (Nazmi and Victora, 2007) found 14 studies reporting higher CRP levels for blacks, Hispanics and South Asians compared to Whites. However, some find minimal income differentials (Alley et al., 2006; McDade et al., 2006; Peterson et al., 2008). Others showed behavioral factors such as smoking, drinking, and obesity explain some of an observed relationship between socioeconomic status and CRP (Koster et al., 2006; Pollitt et al., 2007), especially obesity. Several studies (e.g. (Alley et al., 2006; Panagiotakos et al., 2004)) report inverse associations with education (not always significant).

At the neighborhood level, a few studies document neighborhood socioeconomic and behavioral variation in CRP (Holmes and Marcelli, 2012; Peterson et al., 2008; Pollitt et al., 2007; Schootman et al., 2010) or another inflammation biomarker, interleukin-6 (IL-6) (Peterson et al., 2008; Purser et al., 2008), including an inverse relationship between community SES and CRP (Gallo et al., 2012; Holmes and Marcelli, 2012; Peterson et al., 2008; Pollitt et al., 2007). Peterson and colleagues (2008) find higher levels of another inflammation biomarker (IL-6), but not CRP, in disadvantaged communities, and speculate that factors "such as crowding, noise, unemployment, crime, and pollution contribute to chronic stress."

This paper innovates by testing a specific built environment feature – walkable urban form – which may be associated with CRP through multiple potential mechanisms. The strongest evidence of built environment effects may be for obesity: walkability promotes physical activity (Sallis, 2009), particularly walking. Higher body mass index (BMI) predicts higher CRP (Visser et al., 1999). Types of food available nearby may also influence consumption (Inagami et al., 2006; Morland et al., 2002). Moreover, neighborhood health-related resources including food outlets, recreational facilities, alcohol outlets, and pharmacies, can be shown to influence downstream health and health disparities by influencing health behaviors (Diez Roux and Mair, 2010).

Other built environment mechanisms may simultaneously link CRP with walkable urban form. Walkability may foster positive neighborhood social interaction (Freeman, 2001), which might provide social support (or stressors) which could predict or influence inflammation or co-morbidities. Neighborhood disorder positively and social capital negatively predicted CRP in young, healthy foreign-born Brazilian adults (Holmes and Marcelli, 2012). Because traffic noise and housing quality also vary by urban form, findings that sleep loss (Meier-Ewert et al., 2004; Punjabi and Beamer, 2007) predicts elevated CRP levels are consistent with a possible role for noise. In the CCAHS, traffic stressors are a risk factor for cynical hostility (King, 2012a), elsewhere linked to inflammation (Graham et al., 2006). Finally, walkability results in lower vehicle emissions per person (although dense areas may still have high levels of particulate matter) (Frank and Engelke, 2005). Prior research links traffic-related air pollution with inflammation (Hoffmann et al., 2009; Pope et al., 2004; Rückerl et al., 2007). Furthermore, while residential density is often framed as a key component of walkability and thus unambiguously good policy, evidence linking density with worse (typically mental) health has a long history (Gove et al., 1973; Regoeczi, 2008). Because urban form likely influences a variety of factors which then may influence downstream health, it makes sense to investigate this relationship directly.

This study adds to the literature about contextual effects on health by evaluating evidence about (1) the extent of intra-urban neighborhood variation in CRP compared to related conditions, and (2) whether a specific neighborhood feature – walkable urban form – is associated with lower CRP as theory might predict.

Methods

Data

The Chicago Community Adult Health Study (CCAHS) is a multilevel study of how individual and environmental factors predict health and health disparities, and relevant biological and behavioral pathways. This multistage probability sample of 3,105 adults age 18 and older in the city of Chicago yielded a response rate of 71.8%. Previous research (PHDCN) grouped all 864 Chicago census tracts into 343 neighborhood clusters (NCs) (King, 2012a). Weighted data represent (in terms of race/ethnicity, sex, and age) the 2000 Census Chicago population. CCAHS data collection was approved by University of Michigan Health Sciences and Behavioral Sciences Institutional Review Boards.

Blood was collected once from a subsample of respondents in 80 “focal NCs.” This yielded valid high-sensitivity blood CRP for 610 respondents in 79 NCs (mean=7.7 respondents per NC). The focal NCs, sampled at twice the rate of other NCs, are “a socioeconomically and racially, ethnically heterogeneous subset of Chicago’s neighborhoods” (King et al., 2011), based on stratified random sampling of the 343 NCs according to racial/ethnic composition and socioeconomic status (Sampson and Raudenbush, 1999). Further details on sampling (King et al., 2011) and blood collection (Do et al., 2010) are given elsewhere.

Sociodemographic controls include measures of race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, and non-Hispanic other), sex, age, first-generation immigrant status, educational attainment, and income. BMI was specified by three categories: normal (<25), overweight (25–30), and obese (≥30).

The walkability measures capture elements of the physical layout and content of the built features of the neighborhood. Three aspects of walkable urban form are assessed (similar to Frank et al., 2009): residential density, street connectivity, and land use mix. *Residential Density* is the ratio of 2000 Census population size to residential land area (CMAP, 2006) within a neighborhood. Street connectivity, measured as street intersections per square mile *(Intersection Density)*, makes a city more permeable to walking by reducing the time necessary to reach any potential destination.

Land use mix is measured in two ways, using independent data sources. The first *(Land Use Mix (Area))* is an entropy measure capturing the evenness of allocation among four categories (residential, commercial, institutional, and open), calculated by $-[\Sigma_k (P_k \ln P_k)] / \ln N$, where N is the number of categories and P_k is the proportion of land category k, using data aggregated from aerial photography (CMAP, 2006; author citation). A value of 1 suggests equality in the distribution, and a value of 0 suggests that there is a single dominant land use (entropy does not tell us which use is dominant). Entropy does not increase as the number of categories increases.

The second measure, *Land Use Mix (Face)*, comes from the CCAHS systematic social observation (SSO) (Sampson et al., 2007). For each of the 1,662 blocks on which at least one sampled respondent lived, the rater walked around a block twice, first observing the (usually four) faces of the block, and then the adjacent areas. Eight land uses were noted if present: residential, commercial/business/professional, industrial/warehouse/manufacturing, parking, vacant, institutional, recreational, and waterfront. The final face-based measure is the standardized mean count of land uses on each face within the NC. The face-based measure is more accurate with respect to land uses on faces where respondents live (King, 2012b), while the areal measure has the advantage of covering the entire neighborhood.

Analytic Plan—The analysis assesses how three aspects of walkable urban form may predict CRP. Intra-class correlation (ICC) statistics establish to what extent CRP varies by neighborhood. ICCs are calculated by running a multilevel model which clusters individuals by neighborhood but includes no predictors, and dividing the within-neighborhood variance by the sum of the within- and between-neighborhood variances (Goldstein, 2002). Additional related health outcomes ICCs are given because ICCs are meaningful when compared with other measures within the same sample.

Three analytic models establish that results are generally consistent across modeling frameworks and land use operationalizations. Log transformation is used because CRP is right-skewed (Emerging Risk Factors Collaboration, 2012). Urban form measures are standardized to facilitate comparison. The first two models are multilevel models (Hox, 2010) which group individuals within NCs and adjust for clustering. Model 1 uses a face-based measure, while Model 2 uses an areal measure of land use mix.

Contextual effects estimates may be sensitive to how neighborhoods are defined (Moudon et al., 2006). Thus, an additional modeling framework is used which considers the area (called a buffer) around the respondent (1 kilometer (KM) scale is often used (e.g. Bader et al., 2009; Lovasi et al., 2009; Moudon et al., 2006)). Model 3 is an ordinary least squares regression (clustering-adjusted) on log CRP, adjusted for individual sociodemographics, health behaviors, and 3 measures of walkability within 1 kilometer of the respondent's address: residential density, street connectivity, and land use mix, to test how walkability relates to CRP levels.

Results

In the CCAHS, 42% of respondents had CRP levels over 3 mg/L, a commonly used cutpoint for risk (Ridker, 2003). Sampling-adjusted mean levels were 5.2 for women and 2.8 for men. By comparison, mean CRP concentrations nationally were 5.1mg/L for women and 3.4 mg/L for men (Woloshin and Schwartz, 2005). Chicago is a melting pot (Table 1), with considerable proportions of minorities and immigrants, those with lower education and income, and a broad age range. Chicago neighborhoods are also quite diverse in terms of indicators of walkable urban form, with wide ranges of land use mix and residential density. In this walkable city, mean NC street connectivity (0.52) is more than 1 standard deviation (.

08) above the national mean (0.44) (Escarce et al., 2011). The areal land use mix measures also show diverse land uses.

The ICC, or neighborhood contribution to variance in CRP, is 0.128, higher than the ICCs for HbA1c (0.077), depression (0.061), systolic blood pressure (0.053), diabetes diagnosis (0.046), or total cholesterol (0.046). As individuals tend to live in similar neighborhoods over time (Sharkey and Elwert, 2011), current neighborhood context is an impressive predictor of inflammation, higher than neighborhood variation of various other related health measures.

The analytic models investigate how walkable urban form features may predict CRP, controlling for BMI and extensive sociodemographic measures. Sociodemographic patterning is moderate. Non-Hispanic Blacks (vs. non-Hispanic Whites) and women had higher CRP. No income differentials are observed, but Models 1 and 2 show elevated CRP for those with low education. When compared with the normal (BMI<25) reference group, a highly significant upward trend in log CRP was observed for those in higher BMI categories.

The relationships between urban form variables and CRP are consistent across modeling framework and land use mix specification. In each case, standardized residential density is positively related to CRP, while standardized land use mix is inversely related and potentially protective. Very low ICCs (0.07–0.08) from Models 1 and 2 suggest that most neighborhood variation in CRP has been explained by urban form and sociodemographics.

Discussion

This study adds to the literature about spatial effects on health outcomes in that it investigates how a feature of the physical environment – walkable urban form – may predict a biomarker of inflammation. Only a few population-based analyses include CRP and a clustered design. This sample covers a variety of neighborhood types and multiple racial/ ethnic groups. Walkable urban form is often studied with respect to transportation behavior or physical activity, but infrequently as a predictor of biomarkers.

Finding that residential density is positively associated with CRP in this sample is reason for pause. Walkability has been widely touted as healthy, with density a core prescription. Evidence of greater physical activity in dense areas is consistent, but other factors deserve additional consideration. Air pollution, residential crowding, traffic stress, and other risk factors also increase with density and diversity, and little research has investigated how these risks and benefits may interact. Might there be diminishing health returns to density? If findings of negative associations of density with health outcomes are replicated in other highly dense settings, further investigation is needed to determine the mechanism(s). Pollution, sleep disruption, social and health behavior, psychosocial stress, and even residential selection through non-causal processes are potential explanations which could contravene the hypothesized benefit of walkable urban form for CRP through lowered BMI.

However, physical rather than social explanations seem likely given that in this setting (analyses not shown) and concordant with Peterson and colleagues (2008), socioeconomic characteristics of neighborhoods are not major explanations of variations in CRP. Also, in this study associations between walkability and community social capital measures (e.g. cohesion, control, exchange; (du Toit et al., 2007)) are weak or non-existent (author citation), while social capital measures do not predict CRP (analyses not shown).

This study has limitations. Given the lack of national land use data, studies predicting health using walkable urban form typically cover small areas. The data are cross-sectional, capture only one biomarker of inflammation, and only at a single time point. Still, previous studies have found prior CRP predictive of subsequent cardiovascular health and events (Emerging Risk Factors Collaboration, 2012; Park et al., 2012; Sesso et al., 2003). Further models not shown included controls for health behaviors and other risks/ resources, including depression, stressors, physical activity, sleep, alcohol consumption, and smoking; including these measures but did not substantively alter the association between walkable urban form and CRP. Community socioeconomic status and community and individual social capital were also considered, without affecting the results. Also, respondents' exposures to the built environment were measured only at their residences, but individuals spend varying amount of times at home. Not considering exposures elsewhere potentially results in underestimates of contextual effects (Inagami et al., 2007).

Several circumstances can explain geographic clustering in health measures (Galster, 2012). Perhaps at-risk individuals live in similar neighborhoods either for reasons related to their health (e.g. desire to access services) or not directly relevant to health (e.g. younger adults living near the urban center and coincidentally being healthier). Neighborhoods may directly causally influence health, due to physical exposures (e.g. toxins, noise), accessibility (e.g. ease of navigation, access to health resources), or social interaction (Sampson et al., 2002). Geographic clustering of CRP beyond that of other health measures suggests inflammatory processes may be particularly sensitive to residential environment, and potentially amenable to preventive efforts to improve access to health resources and remove or buffer exposure to health risks and stressors. Better understanding of mechanisms linking the physical environment and CRP is crucial for research and policy.

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Highlights

- Neighborhood conditions may increase inflammation (e.g. C-reactive protein)
- Urban form predicts walking, pollution, and other inflammation risks/resources in prior studies
- We model C-reactive protein and walkable urban form in a representative sample of Chicago adults
- Greater residential density and less land use mix predict higher C-reactive protein

Table 1

Summary Statistics on Covariates (n=610)

Neighborhood Characteristics	NC			1 KM		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
Residential Density (Persons/Sq. Mile)	14976.8	9777.6	3981.1 – 62396.3	14384.5	8656.0	3059.8 – 117273.8
Land Use Mix (Areal)	0.55	0.12	0.23 – 0.92	0,61	0.11	0.28 – 0.92
Land Use Mix (Face)	2.01	0.46	1.19 – 3.75	-	-	-
Intersection Density	0.52	0.03	0.45 – 0.58	0.21	0.05	0.06 – 0.46

Individual Characteristics		**Sample Proportion**[3]	**Mean CRP**
Sex	Female	45.3	5.2***
	Male	54.7	2.8
Race	Non-Hispanic White	39.6	3.1***
	Non-Hispanic Black	34.4	5.8
	Hispanic	21.3	3.9
	Non-Hispanic Other	4.7	1.7
Age	18–29	24.3	2.8***
	30–39	21.2	3.4
	40–49	20.0	4.7
	50–59	15.8	3.9
	60–69	7.5	7.7
	70+	11.2	5.3
Immigration	First Generation	19.9	2.6***
	Second or Later Generation	80.1	4.5
Education	0–11 Years	22.0	4.3***
	12 Years	47.8	5.0
	13+ Years	30.2	2.5
Income	$0–4,900	6.6	4.0
	$5,000–14,999	15.4	3.8
	$15,000–39,999	25.0	4.8
	$40,000+	39.5	3.9

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Individual Characteristics		**Sample Proportion[3]**	**Mean CRP**
	Missing	13.5	3.9
Body Mass Index	<25	29.1	2.1***
	25–30	35.8	3.8
	≥30	35.1	6.1

Chicago Community Adult Health Study, 2001–3;

*** $p < 0.001$

[1] Areal land use mix is an entropy measure capturing the evenness of allocation among five categories (residential, commercial, institutional, open, and other), calculated by $-[\Sigma_k (P_k \ln P_k)] / \ln N$, where N is the number of land use categories and P_k is the proportion of land in each category k.

[2] The final face-based measure is the standardized mean of the count of land uses on each face within the neighborhood cluster.

[3] Sample proportions weighted to reflect population composition of Chicago as reported in Census 2000.

Table 2

Weighted Regressions on Log C-Reactive Protein (*n*=610)

	Model 1	Model 2	Model 3
Form of Regression: ***Spatial Unit:***	**Multilevel Neighborhood Cluster**	**Multilevel Neighborhood Cluster**	**Ordinary Least Squares 1 KM Buffer**
Built Environment			
Residential Area Density	0.11**	0.07*	0.07*
Land Use Mix (Face)	−0.19**		
Land Use Mix (Areal)		−0.13*	−0.12*
Intersection Density	−0.03	−0.05	−0.06
Female	0.45***	0.46***	0.44***
Race (ref=Non-Hispanic White)			
Non-Hispanic Black	0.40**	0.39**	0.37*
Hispanic	0.18	0.17	0.24
Non-Hispanic Other	−0.37	−0.33	−0.30
First Gen. Immigrant	−0.09	−0.08	−0.20
Age (ref=18–29)			
30–39	0.06	0.05	0.06
40–49	0.43**	0.40**	0.38*
50–59	0.32+	0.31+	0.28
60–69	0.57*	0.56*	0.54*
70+	0.47*	0.46*	0.50+
Education (ref=13+ years)			
0–11 Years	0.31*	0.33*	0.19
12 Years	0.39+	0.39+	0.19
Income (ref=$5,000–14,999)			
$0–4,900	−0.06	−0.08	−0.07
$15,000–39,999	0.13	0.13	0.09
$40,000+	0.09	0.10	0.03
Income Missing	0.11	0.10	0.08
Body Mass Index (ref=<25)			
25–30	0.68***	0.68***	0.70***
≥30	1.16***	1.16***	1.19***
Intercept	−0.91***	−0.90***	−0.68**
Akaike Information Criterion	1847.01	1851.47	1793.99
R^2	-	-	0.31
Intra-class Correlation	0.08	0.07	-

+ $p < 0.10$;

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$

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