The legacy of redlining in the effect of foreclosures on Detroit residents' self-rated health

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A B S T R A C T

Historical practices, such as housing discrimination in Detroit, have been shown to have lasting impacts on communities. Perhaps the most explicit example is the practice of redlining in the 1930s, whereby lenders outlined financially undesirable neighborhoods, populated by minority families, on maps and prevented residents from moving to better resourced neighborhoods. Awareness of historical housing discrimination may improve research assessing the impacts of current neighborhood characteristics on health. Using the Detroit Neighborhood Health Study (DNHS), we assessed the association between two-year changes in home foreclosure rates following the 2007–2008 Great Recession, and residents' five-year self-rated health trajectories (2008–2013); and estimated the confounding bias introduced by ignoring historical redlining practices in the city. We used both ecological and multilevel models to make inference about person- and community-level processes. In a neighborhood-level linear regression adjusted for confounders (including percent redlined); a 10%-point slower foreclosure rate recovery was associated with an increase in prevalence of poor self-rated health of 0.31 (95% CI: − 0.02 to 0.64). At the individual level, it was associated with a within-person increase in probability of poor health of 0.45 (95% CI:0.15–0.72). Removing redlining from the model biased the estimated effect upward to 0.38 (95% CI:0.07–0.69) and 0.56 (95% CI:0.21–0.84) in the neighborhood and individual-level models, respectively. Stratum-specific foreclosure recovery effects indicate stronger influence in neighborhoods with a greater proportion of residents identifying as white and a greater degree of historic redlining. These findings support earlier theory suggesting a historical influence of structural discrimination on the association between current neighborhood characteristics and health, and suggests that historical redlining specifically may increase vulnerability to contemporary neighborhood foreclosures. Community interventions should consider historical discrimination in conjunction with current place-based indicators to more equitably improve population health.

1. Introduction

Research on social determinants of health has established neighborhood physical and social conditions as central drivers of residents' health and well-being (Diez Roux, 2001; Duncan and Kawachi, 2018; Kawachi and Berkman, 2003; Krieger, 2011, 2001). Housing is considered a fundamental aspect of neighborhood environments (Thomson et al., 2009), and disparities in housing stability have persisted throughout the United States' history (Coates, 2014; Jacoby et al., 2017). Given the millions of foreclosures filed following the Great Recession in the United States (Pollack and Lynch, 2009), and their disparate impact on low-income and minority residents (Grusky et al., 2011), foreclosures are an important neighborhood exposure to understand with regard to health disparities.

Broadly, interventions aimed at altering current neighborhood environments have shown relatively mixed success for improving the health of residents (Diez Roux and Mair, 2010; Kawachi and Berkman, 2003; Oakes, 2004; Thomson et al., 2009). Some argue these mixed results reflect unintended neighborhood intervention effects (Cunningham, 2001; Fox Gotham, 2001; Wexler, 2001) and/or variability in neighborhood measurement (Diez Roux and Mair, 2010). Further, Vandenbroucke et al. argue that the increasing dominance of causal inference has resulted in a narrowing of methodological approaches and theoretical frameworks used to answer epidemiologic questions. They call for a "pluralistic approach" to epidemiology (Vandenbroucke et al., 2016), which in the context of neighborhoods and health research, should aim to understand complex social processes, with an awareness of exposures at multiple levels of analysis, and their historic influences. Critical assessments of causal claims in health disparities research suggest that confounding by a history of

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structural racism, including discriminatory policies, may also bias estimated neighborhood effects (Bailey et al., 2017; Brown and Smith, 2015; Krieger, 2011; Phelan et al., 2010; Sewell, 2016; VanderWeele and Robinson, 2014). The practice of redlining is just one example of these confounding factors that begins to complicate the narrative on neighborhoods and health.

During the Great Depression, the Home Owners Loan Corporation commissioned maps guiding home lending institutions and preventing non-white racial and ethnic groups from establishing residence in some neighborhoods. Neighborhoods designated undesirable for lenders were outlined in red on these maps, and the practice is now known as "redlining" (Wilson, 2008). While redlining was outlawed under the Fair Housing Act in 1968 (U.S. Department of Housing and Urban Development, 2007), recent research suggests that individual, institutional, and policy-level practices perpetuate systematic segregation of minority groups in the United States (US) (Massey and Denton, 1993); and that similar current and historic practices (e.g. redlining, racial restrictive building covenants, gentrification, predatory lending, etc.) resulted in lasting impacts on the poverty, living environment, and health of current residents (Bailey et al., 2017; Beyer et al., 2016; Jacoby et al., 2017; Massey and Denton, 1993; Mendez et al., 2011, 2012, 2014; Squires, 2017; Zhou et al., 2017).

The Home Owners Loan Corporation practiced redlining in many US cities, including Detroit (Berkovec et al., 1994), and Detroit has a history of dramatic social, economic and racial/ethnic compositional changes over time, making it an important site for investigating the role of historical housing discrimination in shaping communities' health. During World War II, the population and economy of Detroit grew rapidly with the auto industry and manufacturing demands of the War (Krugman, 1991). However, industrial decentralization in the 1950s and reductions in demand, coupled with racial discrimination in housing practices beginning in the 1920s, ultimately weakened the resources and physical quality of many Detroit neighborhoods (Lichter et al., 2015; Sugrue, 1996). Detroit's Home Owners Loan Corporation map is shown in Fig. 1, with the green sections outlining the areas of lowest financial risk, followed by blue then yellow, and finally red areas deemed to be high risk (Dwyer, 2014). Residents of redlined neighborhoods received fewer resources, limiting the economic mobility of minority families (Berkovec et al., 1994; Zenou and Boccard, 2000).

The stories of individual neighborhoods exemplify the complexity of discriminatory housing processes perpetuating segregation (Massey and Denton, 1993). The city's "8 Mile Wall," was constructed in 1940 after the Federal Housing Administration refused to back a loan to build a housing development bordering a Black community. The loan was approved upon construction of the 6-foot tall wall (Clemens, 2006; Sugrue, 1996). The racial compositions of the surrounding neighborhoods have changed, but a divide in resources and economic opportunity remains. While parts of the wall are still standing, activists have painted them and stripped the wall of its role as a racial divider (Ulmer, 2016). In contrast, many redlined neighborhoods were later subjected to urban renewal programs through the Federal Housing Act in 1949, which empowered government agencies to identify blighted properties for repurposing under eminent domain. Urban renewal programs displaced nearly one million Americans, an overwhelming proportion of whom were individuals of minority race or ethnicity (Fullilove and Wallace, 2011). Detroit's Black Bottom neighborhood was one of the only neighborhoods in which Black families could establish residence before the Fair Housing Act, and it was one of the first areas cited for an urban renewal program. Nearly all of Black Bottom's residents were displaced, and current real estate in the neighborhood is largely highly priced (Williams, 2009). Both redlining and urban renewal exacerbated segregation in Detroit (Lichter et al., 2015) and precipitated disparities in neighborhood health and economic opportunity over time. Many formerly redlined neighborhoods are still under resourced, and others have gentrified (Sugrue, 1996), complicating estimation of a homogeneous effect of redlining on current environments and health.

A more recent economic shock, the Great Recession of 2007–2009, led to a steep rise in home foreclosures and abandonment that disproportionately affected minority and low income households in Detroit (Grusky et al., 2011). The American Civil Liberties Union recently sued the city for obscuring eligibility for property tax exemption among the thousands of low income home owners who experienced foreclosures during the crisis (MacDonald and Terry, 2018; Samilton, 2018). Additionally, the National Fair Housing Alliance has initiated a number of lawsuits identifying a racial divide in neighborhood repair efforts on foreclosed properties (National Fair Housing Alliance, 2016). Detroit community advocacy groups have specifically voiced concern that deteriorating homes resulting from economic decline threaten the wellbeing of residents in the most affected neighborhoods (Detroit Blight Removal Task Force, 2014; Loveland, 2017).

Multiple studies suggest that foreclosures impact the wellbeing of families directly affected through financial distress and access to health care (Currie and Tekin, 2015; Pollack and Lynch, 2009). Further, foreclosures may have second-order impacts on families in neighboring households, through stress related to their own economic stability (Arcaya et al., 2013, 2014; Currie and Tekin, 2015; Duran et al., 2018; Houle and Light, 2014) and deterioration of the community and neighborhood physical environment (Cohen et al., 2003; Kelling and Wilson, 1982). However, only a few studies (Duran et al., 2018) have examined how foreclosure recovery (or lack thereof) has affected health (Arcaya, 2017; Duncan and Kawachi, 2018), and none have assessed the potential influence of historical measures of housing discrimination on current foreclosures and health. In the present paper, we examined the association between recent changes in neighborhood-level foreclosure rate and self-rated health among Detroit residents at both the neighborhood and individual levels, and estimated the confounding bias introduced by excluding historical redlining practices in models estimating these associations. We hypothesized that this exclusion would introduce substantial bias to the estimated effects of neighborhood foreclosures. We additionally assessed modification of the effect by redlining history and more recent neighborhood racial composition in order to (1) understand the role of redlining and downstream residential segregation (Massey and Denton, 1993) in the effect of foreclosures on health and (2) inform targeting of potential neighborhood-level public health interventions.

2. Methods

2.1. Study population

The Detroit Neighborhood Health Study (DNHS) includes a population-representative sample of Detroit residents and collected sociodemographic, health, and traumatic experience survey data in five waves spanning 2008–2013. Illustrative of the city's composition, the study sample is predominantly Black with wide variation in socioeconomic status. The DNHS sampling methods and representativeness have been described in detail elsewhere (Goldmann et al., 2011). Participants were included in this analysis if they provided residential location information and self-rated health during at least two study waves, and had no missing covariate data (N = 1471). Detroit's 54 neighborhoods as defined by the City of Detroit Planning and Development Department (Hill and Gallagher, 2002) and operationalized in the DNHS are shown in Fig. 2. University of Michigan affiliates and Detroit residents collaborated to develop the DNHS neighborhood assessment. Resident input and publications documenting community organizing efforts indicate strong affiliation with neighborhood in Detroit (Beshouri, 2013; City of Detroit, 2011; Detroit Neighborhood Health Study Team, 2015). Therefore, in an effort to evaluate environmental factors best aligned with lived experience, we included measures at the spatial scale of the neighborhood in our analyses.

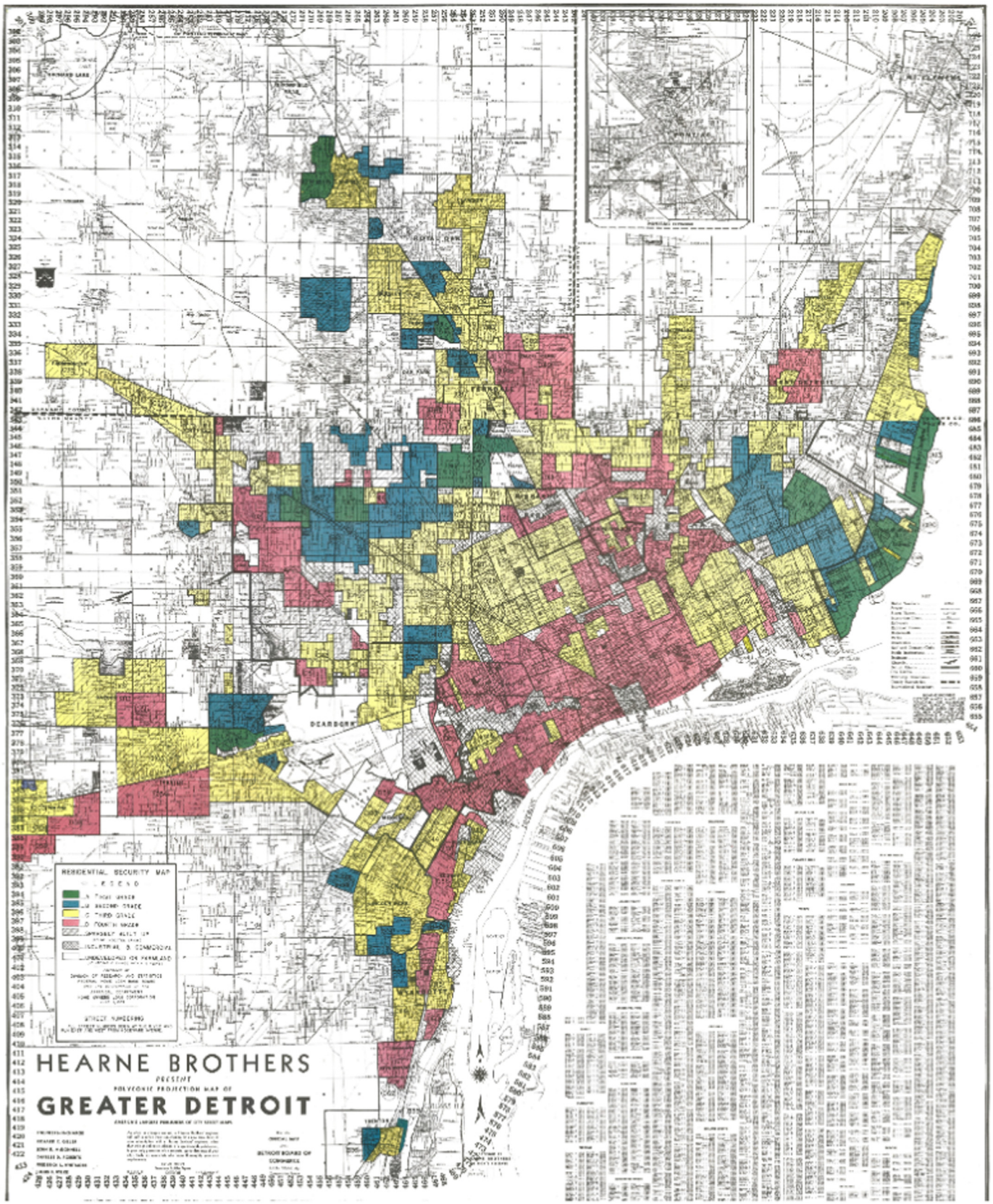

Fig. 1. Detroit home owners loan corporation redlining map, 1939.

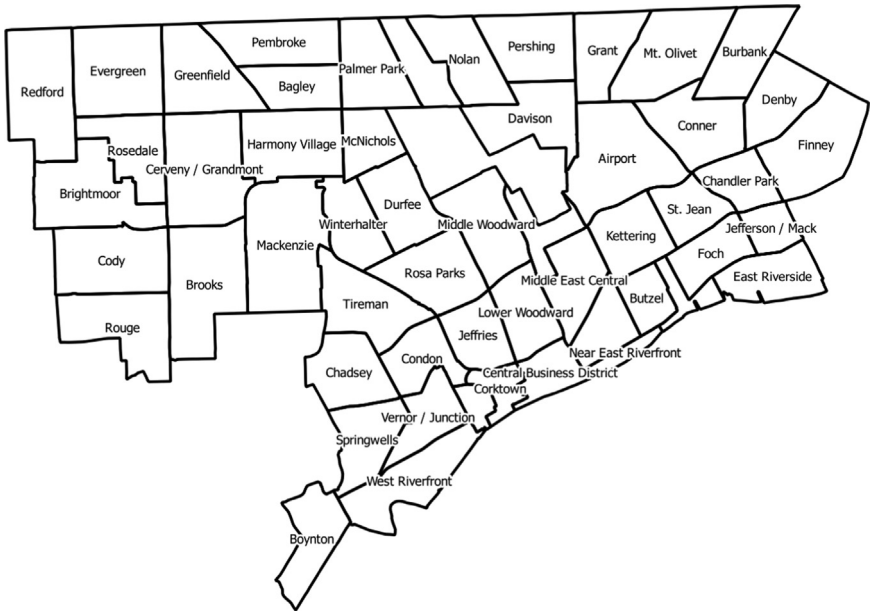

Fig. 2. City of Detroit planning and development department historic neighborhoods.

2.2. Measures

The outcome of interest in the study population, self-rated health, was measured using an indicator of general health shown to predict mortality reliably in several community studies (Idler and Benyamini, 1997). Respondents were asked, "In general, would you say your health is: excellent, very good, good, fair, or poor?" with response categories ranging from 1 = poor to 5 = excellent, at each wave of the survey. For the main analyses, self-rated health was dichotomized as poor (a score of 1) versus not poor (a score of 2 or higher) and was aggregated as neighborhood prevalence of poor health for neighborhood-level analyses.

The exposure of interest, neighborhood foreclosure rate recovery, was derived using data from RealtyTrac, which is a widely validated source for United States real estate statistics and foreclosure trends (RealtyTrac, 2011). We obtained the number of foreclosed properties each year by census block group, the smallest population density-defined geographic unit for which the Census Bureau publishes data (RealtyTrac, 2011; United States Census Bureau, 2013). Home foreclosure rates were measured at the neighborhood level, with block groups nested within the 54 neighborhoods. The rate was constructed as the number of foreclosed properties divided by the number of owner-occupied residences in each year. Owner-occupied residences were selected to avoid misrepresenting areas with high renter populations (Engels, 1999), however, this may result in overestimates of foreclosure rates, as foreclosed homes may be counted in the numerator and not the denominator. Our interpretations assume that measuring change in foreclosure rate the same way across neighborhoods avoids bias from this potential overestimation. Denominator information was obtained from American Community Survey data, collected by the United States Census (United States Census Bureau, 2013). The change in foreclosure rate between 2009 and 2011 was used to represent housing market recovery post-Great Recession.

Proximate confounders—age, gender, and educational attainment—were identified using a directed acyclic graph (Greenland et al., 1999) and collected in the first wave of the survey. Age was collected in years; gender as "male, female, other, or no response"; and educational attainment as "never attended school, kindergarten to 8th grade, some high school, high school equivalency (GED), high school graduate, some college or technical training, college graduate, graduate work, or no response". The literature suggests there are three salient categories in the function of the health benefits of educational attainment (Hummer and Hernandez, 2013). Therefore, educational attainment was modeled using indicator variables for high school and more than high school, with less than high school as referent. For neighborhood-level analyses, respondents contributed data to the neighborhood within which their residential location fell. Age was averaged by neighborhood, gender composition was expressed as percent female, and educational attainment as percent with less than high school degree or equivalent. Each confounder as well as survey wave year to capture time trend were included in statistical models with cubic splines for functional form flexibility (Durrleman and Simon, 1989).

Neighborhood history of redlining was assessed spatially and derived directly from the Home Owners Loan Corporation map from 1939 (Dwyer, 2014). We digitized and linked the historic map with a current map of Detroit, then drew polygons around the areas deemed highest risk (redlined) and calculated their spatial area in square meters. Each of the 54 neighborhoods' area was also calculated in square meters. In analyses, each neighborhood was assigned a measure of redlining. The variable was measured continuously as the proportion of geographic space overlapping historically redlined areas. Digitizing of the historic map and spatial exposure identification were completed using QGIS (QGIS Development Team, 2017). Fig. 3 shows the redlining polygons overlaid with the neighborhood boundaries. Some neighborhoods, like Near East Riverfront, are entirely covered by redlined space and were assigned a redlining variable measure of 1. Others, like Burbank, had no overlap with redlined space and were assigned a 0. Neighborhoods with non-zero nor complete coverage were assigned their proportion. For example, Grant was assigned 0.31.

Census tract-level trends in racial composition from 1930 through 2010 were obtained from the Integrated Public Use Microdata Series (Ruggles et al., 2017). Proportion white was coded as the proportion of census tract residents identified as "white" regardless of parental foreign-born status in 1930, 1970, 1980, 1990, 2000, and 2010. In the same years, proportion minority race or persons of color was coded as the proportion of residents identified as any race other than "white". Race data were not available in the intermediate decades. For regression analyses, racial composition from 2000 was used to represent a more current residential characteristic potentially influenced by redlining, and expressed as percent of residents identifying as white.

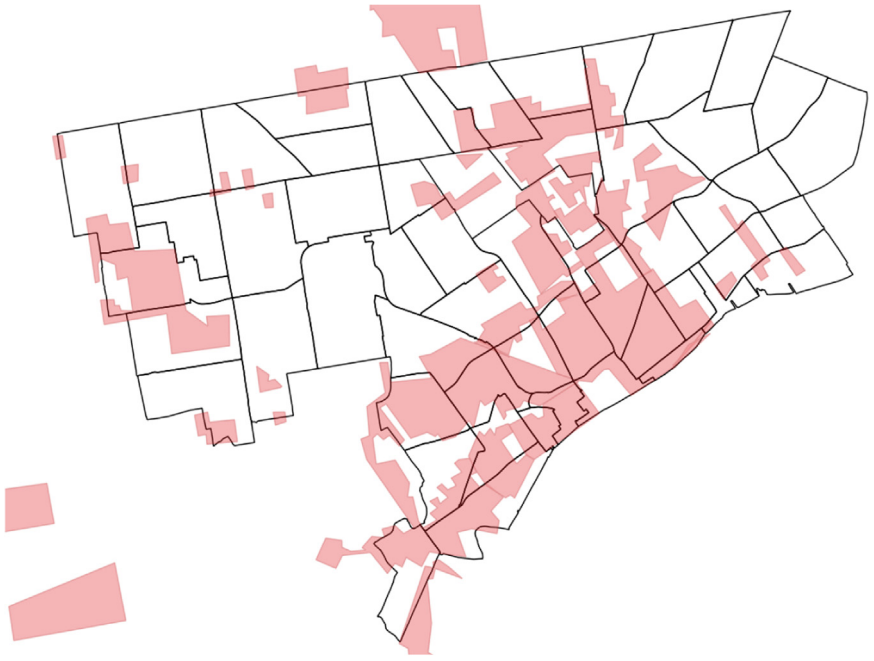

Fig. 3. Redlined areas in city of Detroit planning and development department historic neighborhoods.

2.3. Spatial and statistical analyses

Recent literature calls for social epidemiologists to incorporate analyses at multiple units of analysis, e.g., district-level policies' impacts on individuals' health (Diez Roux, 2017; O'Campo, 2003). While multilevel analyses improve rigor to support causal inference, using them in concert with ecological analyses can inform inference related to implications for entire communities. The main association of interest was that between post-Great Recession (2009–2011) neighborhood foreclosure rate recovery and poor resident self-rated health from 2008 to 2013 at both the neighborhood and individual level. For neighborhood-level analyses, longitudinal linear regressions, adjusted for time trend and proximate confounders (neighborhood age, gender, and educational attainment composition) were run with annual observations nested within each of the 54 neighborhoods. For individual-level analyses, longitudinal, time-adjusted linear regressions with fixed effects for each individual participant were run. Therefore, the effect estimates represent the within-person change in self-rated health over the study period associated with a one unit increase in neighborhood foreclosure rate (adjusting for secular trend). This approach controls for any individual characteristics that do not vary over the study period (e.g. educational attainment) and may confound the relationships assessed (Oakes, 2004).

To quantify confounding bias introduced by neighborhood redlining history, two-step model approaches were used. First the model was run adjusting for the redlining measure and therefore considered to be less biased, then again excluding this variable. Using the change in foreclosure rate's estimated effect when excluding redlining as a covariate, we estimated the degree of bias introduced by ignoring redlining history when assessing the influence of current neighborhood environment on population health. A priori, we defined a 10% change in magnitude of effect from the fully adjusted model to indicate the presence of substantial confounding.

In additional analyses, we assessed associations between the proportion of historically redlined space and foreclosure rate recovery, the proportion of historically redlined space and percent white in 2000, and the proportion of historically redlined space and poor self-rated health at each study wave. As with the main analysis of foreclosure rate recovery and self-related health, estimated effects were generated using multilevel linear regressions. Proximate covariates were not included in these models estimating the effect of redlining, as current neighborhood composition is on the theoretical causal pathway between the redlining and each of the variables tested (foreclosure rate recovery, percent white in 2000, and poor self-rated health). In order to contextualize analyses with regard to residential mobility and racial composition, we mapped census tracts in 1930, 1970, 1980, 1990, 2000, and 2010, showing the percent of residents identified as white and racial minority.

Finally, we assessed whether redlining or current racial composition (2000) modified the effect of foreclosure rate recovery on neighborhood prevalence of poor self-rated health by examining the association within strata of redlining or racial composition. Percent redlined space was dichotomized at 50% and percent white at 30% to enable roughly equally powered strata. If the effect of foreclosure rate recovery on health varies by neighborhood history of redlining, this can inform targeting of housing interventions. The census-based measure of racial composition functions as a proxy for neighborhood variation in demographic makeup, which may be associated with trends in race-based displacement resulting from processes like gentrification. We assessed whether this proxy variable acted as an effect modifier for the association between foreclosure recovery and self-rated health to begin to clarify the role of such processes.

Multiple sensitivity tests were conducted. Self-rated health was modeled continuously (using the average of the 1–5 scores as measured). Models using the dichotomous outcome (probability of poor self-rated health) are presented in results, because of easier interpretability and fidelity to the original, discrete measurement. Because self-rated health was collected at each of the 5 waves, up to 65% of participants missed reporting on this variable during at least one study wave. Therefore, we generated a complete dataset using multiple imputation, adjusted for age, gender, and educational attainment. Estimates were similar between the imputed and un-imputed datasets, with greater precision in the imputed dataset. Those from the original (un-imputed) dataset are reported. As fixed effects analyses ignore between-person variance, which is of substantive interest (Berkman et al., 2014), random effects regressions were also run with measurements over time nested within respondents, and respondents nested within neighborhoods. In order to control for proximate confounders, the random effects analyses adjust for time of outcome measurement, age in

Table 1
Sample characteristics, Detroit historic neighborhoods (N = 54) and Detroit neighborhood health study included participants (N = 1471).

Characteristic	Description
Individual Level	
Age, Median (IQR)	52 (39–61)
Female, N (%)	898 (58)
Educational Attainment, N (%)	
Less than High School	200 (13)
High School or GED	490 (32)
More than High School	850 (55)
Poor self-rated health, N (%)*	
Wave 1 (2008–2009)	424 (27)
Wave 2 (2009–2010)	319 (30)
Wave 3 (2010–2011)	406 (30)
Wave 4 (2011–2012)	286 (34)
Wave 5 (2012–2013)	116 (33)
Neighborhood Level	
Foreclosure Rate (per 100 households) Change 2009–2011, Median (IQR)	− 0.80 (−2.98 to −0.48)
Percent of residents identifying as white in 2000, Median (IQR)	17 (7–28)
Percent Overlap with Historic Redlining, Median (IQR)	14 (1–56)

* Represents the proportion of those without missing data for the measure at each wave.

years, gender, and educational attainment. Estimated effects of neighborhood foreclosure on individual self-rated health over time using random effects regressions were very similar to those obtained from the fixed effects estimates. As the fixed effects approach is more conservative, estimates from this approach are reported. Statistical analyses were completed using R (R Core Team, 2013).

3. Results

DNHS respondents lived in each of the 54 historic neighborhoods and each historically redlined area within Detroit's city limits. Sample characteristics are shown in Table 1. Participants were a median of 52 years of age (IQR: 39–61 years) at baseline. 58% of respondents were female, and 55% had greater than a high school education. The proportion reporting poor general health increased over the study period, with 27% reporting poor health in Wave 1% and 33% in Wave 5. Most neighborhoods experienced foreclosure rate recovery between 2009 and 2011, with a median decline of − 0.8 (IQR: −2.98, −0.48), or 0.8 fewer foreclosures per 100 owner-occupied households over the 2 year period. The median percent of neighborhood residents identifying as white was 17 (IQR: 7–28), and percent overlap with redlined space was 14 (1−56).

Post-Great Recession foreclosure recovery, expressed as changes in rates between 2009 and 2011 are shown in Fig. 4A. Neighborhoods shaded lighter had faster recoveries in foreclosure rates over the study period compared with darker shaded neighborhoods. Neighborhood change in prevalence of poor self-rated health over the study period is shown in Fig. 4B. Areas with darker shading experienced increases in the prevalence of poor health, while lighter shading indicates decreases.

Estimates from regression analyses are displayed in Table 2. At the neighborhood level, slower foreclosure rate recovery was associated with a higher prevalence of poor self-rated health over the study period. A 10%-point slower foreclosure rate recovery was associated with a 0.31 (95% CI: −0.02, 0.64) increase in prevalence of poor self-rated health. Similarly at the individual level, a 10%-point slower neighborhood foreclosure rate recovery was associated with a 0.56 (95% CI:0.21, 0.84) increase in the within-person probability of experiencing poor self-rated health over the study period.

Removing redlining from the model substantially biased the effect estimates of foreclosure rate recovery. The effect estimate increased by almost 23% when omitting redlining from the adjustment set in neighborhood-level analyses and 20% in individual-level analyses. Redlining history was strongly associated with post-Recession foreclosure rate recovery and self-rated health. A 10%-point increase in the neighborhood's redlined area was associated with a 7.3 (95% CI:1.87, 12.71) slower foreclosure rate recovery. This translates to 7 foreclosures more per 100 owner-occupied units over the 2-year period. A 10%-point increase in redlined area in a neighborhood was associated with a 0.56 (95% CI: −0.10, 1.28) increase in neighborhood prevalence of poor self-rated health and an increase of 0.23 (95% CI: −0.06, 0.57) in the within-person probability of experiencing poor self-rated health over the study period. Redlining history was weakly associated with racial composition in 2000, with a 10%-point increase in redlined area associated with a 0.04 (95% CI: −0.37, 0.55) increase in percent white.

Fig. 5 shows racial composition changes in Detroit over the decades. The maps show that minority family residences were, by law (Sugrue, 1996; Williams, 2009), concentrated in one area in 1930 but made up the majority of residences within the city by 2010. On the other hand, nearly all Detroit census tracts were mostly white in 1930 but by 2010 the majority of white census tracts were outside city boundaries. On top in blue (from left to right), each map shows the percent of census tract residents identifying as minority race in 1930, 1970, 1980, 1990, and 2010. Below in red (from left to right), each map shows the percent of residents identifying as white during the same years. The map for 2000 is not shown since 2000 and 2010 were visually very similar. Census tracts shaded darker represent a higher percentage of each respective racial group.

Stratum-specific neighborhood-level analysis results are shown in Table 3. Within redlining strata, the effect of foreclosure rate recovery on self-rated health was stronger in areas with redlining history. The effect was greater in neighborhoods with 50% or greater redlined space

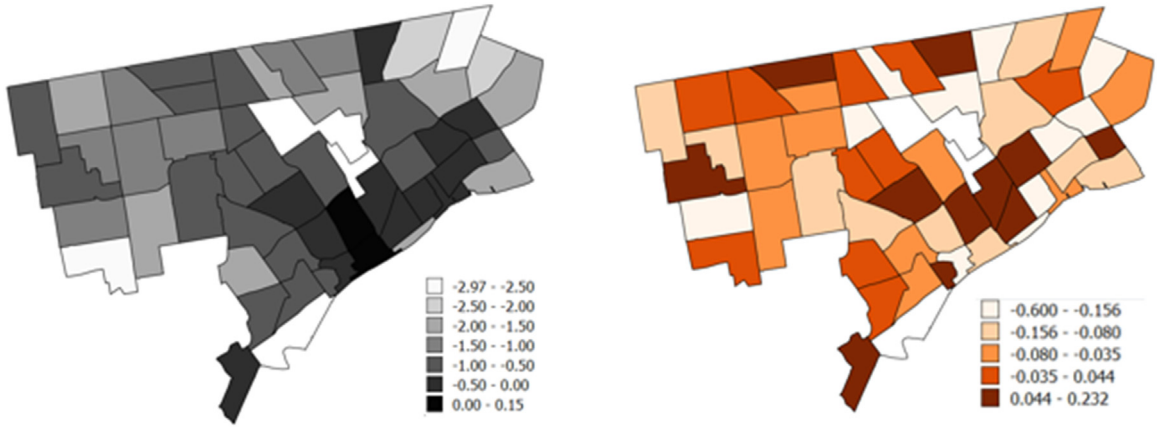

Fig. 4. A. Change in Neighborhood Foreclosure Rate 2009– 2011; Fig. 4B. Change in Prevalence of Poor Self-rated Health 2008–2012.

Table 2
Estimated associations between redlining, foreclosure rate, and poor health; Detroit neighborhoods (N = 54) and Detroit neighborhood health study included participants (N = 1471).

Model	Estimate (95% CI)	% Change in estimate
Effect of Foreclosure Rate Recovery[1]		
Neighborhood-Level		
Foreclosure Rate Recovery→Poor Self-Rated Health*	0.31 (−0.02 to 0.64)	
Foreclosure Rate Recovery→Poor Self-Rated Health**	0.38 (0.07–0.69)	22.6
Individual-Level		
Foreclosure Rate Recovery→Poor Self-Rated Health***	0.45 (0.15–0.72)	
Foreclosure Rate Recovery→Poor Self-Rated Health****	0.56 (0.21–0.84)	19.6
Redlining Associations[2]		
% Redlined Area→Foreclosure Rate Recovery	7.32 (1.87–12.71)	
% Redlined Area→Percent white in 2000	0.04 (−0.37 to 0.55)	
% Redlined Area→Poor Self-Rated Health (Neighborhood)	0.56 (−0.10 to 1.28)	
% Redlined Area→Poor Self-Rated Health (Individual)	0.23 (−0.06 to 0.57)	

* Adjusted for time, percent female, percent with less than high school educational attainment, median age, and *percent redlined.*
** Adjusted for time, percent female, percent with less than high school educational attainment, and median age.
*** Adjusted for time, individual fixed effects, and *percent redlined.*
**** Adjusted for time and individual fixed effects.
[1] Estimated change associated with a 10%-point increase in foreclosure rate recovery.
[2] Estimated change associated with a 10%-point increase in proportion redlined space.

(β = 0.41 (95% CI: −0.49, 1.31)) relative to neighborhoods with less than 50% (β = 0.28 (95% CI: −0.12, 0.68)). However, these estimates were fairly imprecise and the 95% confidence interval for each stratum includes the estimated effect for the other. In terms of racial composition, the effect of foreclosure rate recovery on self-rated health was stronger in neighborhoods with a greater proportion of residents identifying as white. Areas in which 30% of residents or greater identified as white had a stronger effect (β = 0.68 (95% CI: −0.17, 1.53)) relative to neighborhoods with less than 30% identifying as white (β = 0.04 (95% CI: -0.22, 0.31)). Similarly, these estimates are imprecise, but the magnitude of difference in effect is greater and substantively meaningful. Estimates from all sensitivity tests are included in Appendix 1.

4. Discussion

In Detroit, areas with slower post-Great Recession foreclosure recovery have a higher prevalence of poor self-rated health among adults. This finding is consistent with literature suggesting that foreclosures have second-order impacts on neighbors' health (Arcaya et al., 2013, 2014; Currie and Tekin, 2015; Houle and Light, 2014). Further, our results add support to the body of literature documenting the continued legacy of redlining in current populations (Bailey et al., 2017; Beyer et al., 2016; Gee, 2002; Jacoby et al., 2017; Lichter et al., 2015; Wilson, 2008; Zhou et al., 2017) and specifically among residents of Detroit (Dwyer, 2014; Sugrue, 1996). Redlining history was associated with both slower neighborhood foreclosure recovery and poorer self-rated health among participants. The roles of redlining and foreclosure recovery in associations with health suggest that social determinants of health capture the combined effects of historical factors that influence health through multiple mechanisms (Diez Roux and Mair, 2010; Osypuk and Acevedo-Garcia, 2010; VanderWeele and Robinson, 2014). We find evidence to suggest that historic redlining confounds the relationship between foreclosure recovery and health. Ignoring redlining in regression models induced substantial bias to the estimated effect of foreclosure recovery (20–23% change).

The effect of slower foreclosure recovery on poor self-rated health was stronger in areas with more redlined space. Our findings demonstrate the complexity of the main association between foreclosures and health. Neighborhoods with more redlining had the lowest 2009 foreclosure rates, likely because imbalances in lending resulted in less home ownership (Brescia, 2009; Fisher, 2009; Shapiro et al., 2013). Areas with low 2009 foreclosure rates experienced a lower degree of recovery by 2011. Among neighborhoods with higher 2009 foreclosure rates (and therefore opportunity for a greater recovery), those with more redlining had disproportionately slower recovery than areas with less redlined space. The effect of slower foreclosure recovery on poor self-rated health was also stronger in neighborhoods with a higher percentage of white residents. The smaller effect in predominantly minority neighborhoods may be similarly driven by a smaller degree of variance in foreclosure change, with 2011 foreclosure rates remaining highest in neighborhoods with less than 30% of residents identifying as

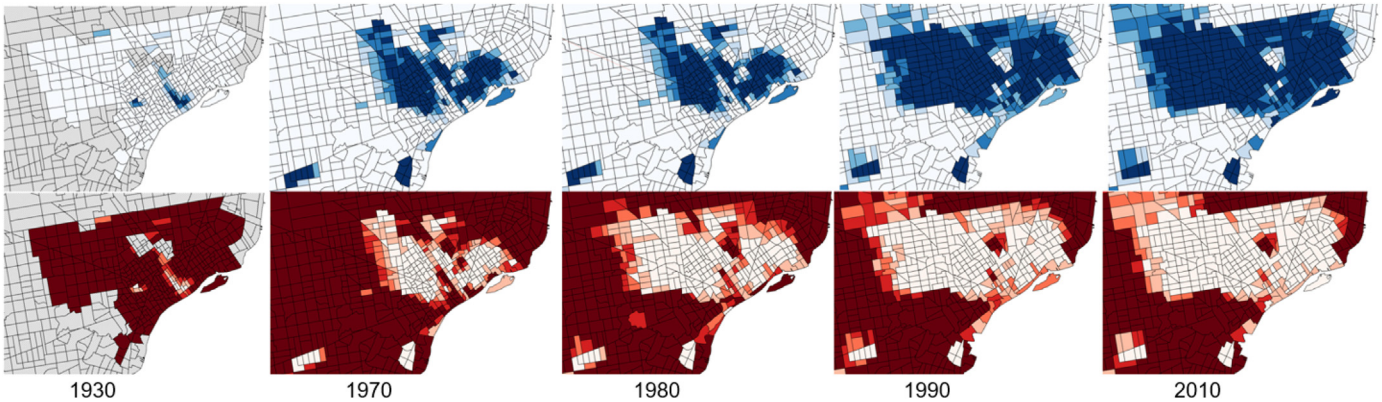

Fig. 5. Percent of residents identifying as racial minority/persons of color (blue) and white (red) in 1930, 1970, 1980, 1990, and 2010. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Table 3
Estimated associations between foreclosure rate recovery and poor health within strata of historic redlining and racial composition in 2000; Detroit neighborhoods (N = 54).

Model	Estimate (95% CI)
Redlining Stratum-Specific Effects of Foreclosure Rate Recovery[1]	
Foreclosure Rate→Prevalence Poor Self-Rated Health (less than 50% redlined space)*	0.28 (−0.12 to 0.68)
Foreclosure Rate→Prevalence Poor Self-Rated Health (50 or higher percent redlined space)*	0.41 (−0.49 to 1.31)
Racial Composition Stratum-Specific Effects of Foreclosure Rate Recovery[1]	
Foreclosure Rate→Prevalence Poor Self-Rated Health (30 or higher percent white)**	0.68 (−0.17 to 1.53)
Foreclosure Rate→Prevalence Poor Self-Rated Health (less than 30% white)**	0.04 (−0.22 to 0.31)

* Adjusted for time, percent female, percent with less than high school educational attainment, median age, and *percent redlined*.
** Adjusted for time, percent female, percent with less than high school educational attainment, and median age.
[1] Estimated change associated with a 10%-point increase in foreclosure rate recovery.

white. It is also possible that this modification is the result of community cohesion and solidarity buffering negative environmental impacts (Arcaya, 2017; Berkman et al., 2014). However, we were unable to test this hypothesis in our study. Future studies should aim to examine levels of stress and how they might interact with the negative impacts of foreclosure on health among minorities within differently composed neighborhoods.

No statistical model alone can capture the complexities of the foreclosures and health associations. To develop well-informed policy to mitigate health disparities, conceptually and theoretically informed frameworks including historical perspective, are required to motivate empirical approaches. Redlining is only one, easily measurable structural factor contributing to disparities. Therefore, the potential impacts of redlining on health cannot be interpreted in isolation and should not be oversimplified. The varied housing policies, power structures, and cultural practices shaping redlined neighborhoods and their residents should be considered in addressing the legacy of this and other discriminatory practices with regard to health (Osypuk and Acevedo-Garcia, 2010). Detroit's neighborhoods experienced varied trends in lending and renting practices, policies, racial composition, and discrimination at many levels (Massey and Denton, 1993; Sugrue, 1996), and redlining continues to influence them.

Probably the largest scale related process in understanding the impacts of redlining is urban renewal, which was not readily operationalized for this analysis. While many redlined neighborhoods remain under resourced and house current generations of families whose residence dates back to the 1930s, there are spaces like Black Bottom, with large scale displacement and reinvestment (Sugrue, 1996; Williams, 2009). The displacement of minority families is reflected in Fig. 5. Black Bottom was one of the only neighborhoods in which Black families could establish residence and businesses in the 1920s. It was also one of the hardest hit economically during the Great Depression. Urban renewal programs in the 1960s dismantled Black Bottom and displaced residents, mainly to large housing projects. The area now houses a section of major highway as well as commercial buildings and luxury condominiums (Sugrue, 1996; Williams, 2009). Black Bottom is the corridor of predominantly minority residents in the 1930 map in Fig. 5, reflecting legal restrictions on minorities' residential location choices (Wilson, 2008). Urban renewal-inflicted displacement is also evident in Fig. 5, as Black Bottom is no longer discernable by 1970. Similar processes continue to influence segregation and disparities. Reverse redlining, wherein lenders predatorily target higher prices to neighborhoods deemed "high risk" rather than deny loans, is still documented in current lending (Brescia, 2009; Fisher, 2009), and similar methods of restricting commerce occurred in tandem with redlining. For example, the Curtis Publishing Company generated "bluelining" maps of cities guiding newspaper circulation, transportation spending, and other consumer goods to residential areas deemed to be better markets (Hill, 2017). The present analysis begins to address one historic component of the neighborhoods and health framework, but it remains an oversimplification. Several measures such as urban renewal and complex processes like gentrification should be quantified to expand research examining neighborhood-level discrimination.

This study has several strengths. It is the first to include redlining in an analysis of the current neighborhood environment and health. We demonstrated that the use of historical data sources can help better inform assessments of neighborhood effects on health. Further, we conducted this assessment in a population-based sample of Detroit residents using individual- and neighborhood-level units of analysis, and estimated within-person effects controlling for all time invariant characteristics and relevant time variant characteristics. The analysis is limited by loss to follow-up in DNHS, which, while comparable to some other large prospective studies, is over 60% (Schulz et al., 2006). It likely reflects the outmigration (white flight) that occurred during this period of economic downturn (Sugrue, 1996) and therefore selectivity of participants who stayed in Detroit. While associations showed little sensitivity to analysis using imputed follow-up outcome values, factors influencing loss to follow-up for which we did not control in imputation may still bias estimates. Additionally, while our measure of foreclosure rate accounts for owner occupancy by only including owner-occupied properties in the denominator, it does not capture the impacts of other housing displacement stressors more relevant to renters, like eviction (Desmond, 2016). Further, the estimated effects of foreclosure recovery on poor self-rated health is likely to be vulnerable to bias related to unmeasured confounding by historical factors other than redlining, like urban renewal, racial restrictive covenants, etc. Similarly, the change in estimate we attribute to failure to adjust for redlining history may be due to such unmeasured factors. Finally, the DNHS population only represents residents of Detroit, limiting our ability to make inference about the factors driving macro-level segregation in the entire metropolitan area (Lichter et al., 2015; Massey and Denton, 1988; Osypuk and Acevedo-Garcia, 2010). Despite these limitations, our findings support theory that historic determinants of racial segregation have lasting impacts on population health (Krieger, 2011).

This work highlights that structural inequalities underlie health disparities. Despite this, epidemiologic research often ignores historical context. We asked: "what is the effect of neighborhood foreclosure rate recovery on self-rated health?" using a standard causal inference framework approach, adjusting for proximate covariates—current neighborhood characteristics. However, contemporary neighborhood variables of interest are often strongly related to distal, historical factors (Krieger, 2011; VanderWeele and Robinson, 2014). A history of processes perpetuating inequality through residential segregation compound one another to influence health (Diez Roux and Mair, 2010), and as such, failure to consider the historical context is misleading. Interpreting naïve, a-historical analyses as estimates of causal effects may imply that changing the current physical environment alone will substantially improve health equity, encouraging development of less effective interventions. Further, historical exposures can exert powerful effects on health through many mechanisms (Phelan et al., 2010; VanderWeele and Robinson, 2014). Fundamental causes theory suggests that if we intervene on a proximate exposure, like current

Table A1
Estimated associations between redlining, foreclosure rate, and poor health; Detroit neighborhood health study included participants (N = 1471) using random effects models.

Model	Estimate (95% CI)	% Change in Estimate
Effect of Foreclosure Rate Recovery[1]		
Individual-Level		
Foreclosure Rate Recovery→Poor Self-Rated Health*	0.48 (0.19–0.77)	
Foreclosure Rate Recovery→Poor Self-Rated Health**	0.62 (0.29–0.95)	29.2

[2]Estimated change associated with a 10%-point increase in proportion redlined space.
* Adjusted for time, age, gender, educational attainment, and *percent redlined*.
** Adjusted for time, age, gender, and educational attainment.
[1] Estimated change associated with a 10%-point increase in foreclosure rate recovery.

Table A2
Estimated associations between redlining, foreclosure rate, and average self-rated health; Detroit neighborhoods (N = 54) and Detroit neighborhood health study included participants (N = 1471).

Model	Estimate (95% CI)	% Change in Estimate
Effect of Foreclosure Rate Recovery[1]		
Neighborhood-Level		
Foreclosure Rate Recovery→Average Self-Rated Health*	−0.52 (−1.13 to 0.13)	
Foreclosure Rate Recovery→Average Self-Rated Health**	−0.66 (−1.27 to 0.05)	26.9
Individual-Level		
Foreclosure Rate Recovery→Average Self-Rated Health***	− 0.68 (−1.01 to −0.35)	
Foreclosure Rate Recovery→Average Self-Rated Health****	− 0.82 (−1.23 to −0.41)	20.6
Redlining Associations[2]		
% Redlined Area→Average Self-Rated Health (Neighborhood)	− 0.90 (−2.26 to 0.46)	
% Redlined Area→Average Self-Rated Health (Individual)	− 0.73 (−1.79 to 0.33)	

* Adjusted for time, percent female, percent with less than high school educational attainment, median age, and *percent redlined*.
** Adjusted for time, percent female, percent with less than high school educational attainment, and median age.
*** Adjusted for time, individual fixed effects, and *percent redlined*.
**** Adjusted for time and individual fixed effects.
[1] Estimated change associated with a 10%-point increase in foreclosure rate recovery.
[2] Estimated change associated with a 10%-point increase in proportion redlined space.

foreclosure rate, health disparities will persist through other, unspecified pathways. It is possible that the effects of redlining and similar discriminatory practices exhibit the "replacement" phenomenon described by Link and Phelan and perpetuate health disparities through many mechanisms (Phelan et al., 2010) including neighborhood foreclosure rate, residential segregation, social cohesion, and others.

We demonstrate that elements of historical discrimination can be acknowledged and measured in order to better understand the determinants of health disparities. While we cannot directly intervene on historical exposures, future research should aim to inform policy and intervention with an awareness of the historical factors potentially limiting the effectiveness of current environmental improvements. This awareness can help identify better targeted and more robust neighborhood health interventions (Vandenbroucke et al., 2016). For example, foreclosure responses in Detroit have included aesthetic and structural improvements to vacant properties. These types of interventions have been effective in improving the value of neighboring properties but not mitigating health disparities (Detroit Blight Removal Task Force, 2014; Hill, 2015). More effective responses to reduce health disparities will also include awareness of historical discriminatory practices. Some examples include (but are not limited to): 1) community-driven identification of the lenders most likely to foreclose on individual home owners over the last two decades in Detroit (MacDonald and Kurth, 2015) and 2) litigation to reclaim property and secure reparations related to unjust foreclosures (MacDonald and Terry, 2018; Samilton, 2018). Such interventions demonstrate understanding of the historical determinants of racial and socioeconomic differences in foreclosures, and begin to address the combined impacts of discrimanatory practices and policies (Coates, 2014; Williams and Collins, 2004).

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Author contributions

Elizabeth McClure conceptualized and designed the study, drafted the initial manuscript, analyzed the data, created the tables and figures, assisted with the literature review synthesis, and approved the final manuscript as submitted.

Lydia Feinstein provided content to the analysis, assisted with the literature review, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Evette Cordoba assisted with the literature review, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Christian Douglas advised on analytical strategy, provided content

Table A3
Estimated associations between redlining, foreclosure rate, and poor self-rated health; Detroit neighborhoods (N = 54) and Detroit neighborhood health study included participants (N = 1471) imputed dataset.

Model	Estimate (95% CI)	% Change in Estimate
Effect of Foreclosure Rate Recovery[1]		
Neighborhood-Level		
Foreclosure Rate Recovery→Poor Self-Rated Health*	0.30 (0.03–0.57)	
Foreclosure Rate Recovery→Poor Self-Rated Health**	0.38 (0.11–0.65)	26.7
Individual-Level		
Foreclosure Rate Recovery→Poor Self-Rated Health***	0.44 (0.22–0.66)	
Foreclosure Rate Recovery→Poor Self-Rated Health****	0.57 (0.32–0.83)	29.5
Redlining Associations[2]		
% Redlined Area→Poor Self-Rated Health (Neighborhood)	0.57 (0.10–1.04)	
% Redlined Area→Poor Self-Rated Health (Individual)	0.23 (0.01–0.45)	

* Adjusted for time, percent female, percent with less than high school educational attainment, median age, and *percent redlined.*
** Adjusted for time, percent female, percent with less than high school educational attainment, and median age.
*** Adjusted for time, individual fixed effects, and *percent redlined.*
**** Adjusted for time and individual fixed effects.
[1] Estimated change associated with a 10%-point increase in foreclosure rate recovery.
[2] Estimated change associated with a 10%-point increase in proportion redlined space.

to the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Michael Emch advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Whitney Robinson assisted in conceptual and analytic design, advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Sandro Galea contributed to the parent study design and data collection, assisted in conceptual and analytic design, advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Allison Aiello contributed to the parent study design and data collection, provided overall supervision and guidance of the present analysis, assisted in conceptual and analytic design, advised on the analytic strategy, provided commentary on the analysis, contributed to editing of the manuscript, and approved the final manuscript as submitted.

Appendix 1

See Tables A1–A3 here.

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