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The legacy of structural racism: Associations between historic redlining, current mortgage lending, and health

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ABSTRACT

Structural racism, which is embedded in past and present operations of the U.S. housing market, is a fundamental cause of racial health inequities. We conducted an ecologic study to 1) examine historic redlining in relation to current neighborhood lending discrimination and three key indicators of societal health (mental health, physical health, and infant mortality rate (IMR)) and 2) investigate sustained lending disinvestment as a determinant of current neighborhood health in one of the most hypersegregated metropolitan areas in the United States, Milwaukee, Wisconsin. We calculated weighted historic redlining scores from the proportion of 1930s Home Owners' Loan Corporation residential security grades contained within 2010 census tract boundaries. We combined two lending indicators from 2018 Home Mortgage Disclosure Act data to capture current neighborhood lending discrimination: low lending occurrence and high cost loans (measured via loan rate spread). Using historic redlining score and current lending discrimination, we created a 4-level hierarchical measure of lending trajectory. In Milwaukee neighborhoods, greater historic redlining was associated with current lending discrimination (OR = 1.73, 95%CI: 1.16, 2.58) and increased prevalence of poor physical health (β = 1.34, 95% CI: 0.40, 2.28) and poor mental health (β = 1.26, 95%CI: 0.51, 2.01). Historic redlining was not associated with neighborhood IMR (β = −0.48, 95%CI: −2.12, 1.15). A graded association was observed between lending trajectory and health: neighborhoods with high sustained disinvestment had worse physical and mental health than neighborhoods with high investment (poor physical health: β = 5.33, 95%CI: 3.05, 7.61; poor mental health: β = 4.32, 95%CI: 2.44, 6.20). IMR was highest in 'disinvested' neighborhoods (β = 5.87, 95%CI: 0.52, 11.22). Our findings illustrate ongoing legacies of government sponsored historic redlining. Structural racism, as manifested in historic and current forms of lending disinvestment, predicts poor health in Milwaukee's hypersegregated neighborhoods. We endorse equity focused policies that dismantle and repair the ways racism is entrenched in America's social fabric.

Introduction

A wide body of research has connected health inequities to the social determinants of health (Solar & Irwin, 2010). National and international bodies have recognized that addressing social determinants of health, including economic stability, education, social and community context, and the neighborhood and environment, plays a key role in reducing health inequities. However, without considering structural factors "upstream" of social determinants of health, such as structural racism, efforts to eliminate health inequities will continue to fall short (Birn et al., 2017; Solar & Irwin, 2010).

Structural racism represents the myriad of ways in which racial discrimination is embedded in society through interlocking social, legal, and political institutions and systems, which in turn, reinforce values, beliefs, norms, and resource distribution that privilege whiteness and white racialized identity (Bailey et al., 2017). Structural racism is a

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fundamental cause of racial health inequities; while a product of history, it adapts to new contexts over time to recreate the conditions that give rise to poor health for racially minoritized populations (Phelan & Link, 2015; Williams et al., 2019).

America's racial hierarchy is maintained through various mechanisms, including state-sanctioned violence, political exclusion, and incarceration (Bailey et al., 2017). Structural racism permeates systems of education, housing, employment, health care, and criminal justice, impacting resource distribution and access to opportunity. Structural racism operates by reinforcing unequal social, economic, and environmental conditions, which ultimately drive poor health. Communities of color face a disproportionate burden of environmental hazards and reduced access to quality food, transportation, health care, educational and employment opportunities, recreation and preventative health services (Bailey et al., 2017). Racial residential segregation, housing inequality, concentrated economic hardship, and the co-occurrence of other social conditions linked to poverty are a result of decades of racism and disinvestment in communities of color (Williams et al., 2019).

A robust body of literature has delineated how structural racism operates in the U.S. to influence health (Bailey et al., 2017; Gee & Ford, 2011). Few studies, however, have empirically examined structural racism as a determinant of health or health inequities (Bailey et al., 2017; Williams et al., 2019). The limited studies empirically examining structural racism have found a relationship with health outcomes. Indeed, adverse birth and cardiac health outcomes in Black Americans have been associated with multiple state-level indicators of structural racism, including education, employment, income, incarceration, judicial treatment, and political representation (Lukachko et al., 2014; Pabayo et al., 2019;Wallace et al., 2017; Wallace et al., 2015). The abolition of Jim Crow laws, a form of structural racism that legalized racial discrimination across institutions, was linked to improved health outcomes for Black Americans, including reductions in infant mortality (Chay & Greenstone, 2000;Krieger et al., 2013). The Index of Concentrations at the Extremes, a measure of spatial social polarization expanded to include dimensions of racialized economic segregation, has been associated with racial inequities in birth outcomes, premature mortality, and diabetes mortality (Chambers et al., 2019; Krieger et al., 2016). Many studies on health effects of racial residential segregation, however, do not discuss segregation as a historical and ongoing product of and means to reinforce structural racism.

The Home Owners' Loan Corporation (HOLC) was a U.S. federal agency created in the 1930s that graded mortgage investment risk of neighborhoods across the United States between 1934 and 1940 (Hillier, 2005). HOLC residential security maps standardized racially based appraisal methods and pioneered the institutional logic of residential 'redlining'—the systematic implementation of discriminatory lending practices that denied mortgages in neighborhoods of color while insuring mortgages and reinvestment in predominantly white neighborhoods (Hillier, 2003; Hillier, 2005; Rothstein, 2017).

Racially discriminatory lending policies and practices have systematically shaped access to wealth, strategically patterned community (dis)investment, and deliberately maintained racial residential segregation. Neighborhoods today are a manifestation of a myriad of racist housing policies and practices that have fundamentally shaped housing tenure, the built environment, and health. The race-based discrimination captured in HOLC residential security maps is further reinforced by place-based resource distribution, creating trajectories of neighborhood investment and disinvestment that have continued for the decades since redlining was first introduced (Krieger, Van Wye, et al., 2020).

The impact of HOLC maps on mortgage risk assessments did not end 80 years ago. Rather, redlining has continued to influence racialized perceptions of neighborhood value and practices that have perpetuated racial inequities in lending. After the HOLC ceased in 1951, institutionalized racism persisted across institutions, including the Federal Housing Administration, through predatory lending policies, racially restrictive covenants, exclusionary zoning, blockbusting, and many other racialized steering practices (Rothstein, 2017; Taylor, 2018). Despite legally prohibiting redlining in the 1960s, lending discrimination has evolved. Racialized perceptions of value contributed to the devaluation of property and housing stock in neighborhoods of color (Taylor, 2019). In pursuit of profit, the real estate and banking industries have continued to engage in exploitative practices that reinforced the conflation of "race" and "risk" (Taylor, 2019). Decades of racism in the housing market have prevented people of color, particularly Black Americans, equal access to capital, low cost loans, and home ownership (Rothstein, 2017; Taylor, 2018). HOLC residential security grades have been found to be associated with reduced home ownership rates and house values, documenting the lasting impact of redlining on urban development through disinvestment and reduced credit access (Aaronson et al., 2020). However, many studies examining the legacy of redlining on current lending lack local historical context and have largely been siloed to economics.

Several recent studies have explored the legacy of HOLC residential security maps on present-day health outcomes and social determinants of health (Hoffman et al., 2020; Jacoby et al., 2018; Krieger, Van Wye, et al., 2020; Krieger, Wright, et al., 2020; McClure et al., 2019; Namin et al., 2020; Nardone et al., 2020). HOLC 'redlining' has been associated with pre-term birth (Krieger, Van Wye, et al., 2020), later stage cancer diagnosis (Krieger, Wright, et al., 2020), higher rates of emergency department visits for asthma (Nardone et al., 2020), and poorer self-reported health (McClure et al., 2019). HOLC 'redlining' has also been associated with neighborhood determinants of health, including alcohol outlet clusters (Trangenstein et al., 2020), urban violence (Jacoby et al., 2018), less tree canopy and more airborne hazards (Namin et al., 2020), and higher intra-urban heat (Hoffman et al., 2020). McClure et al. (McClure et al., 2019) is the only other study that we are aware of that has evaluated HOLC 'redlining' in relation to current housing instability (i.e., post Great Recession foreclosure rates) and health. To our knowledge, no studies have examined the legacy of structural racism in the housing market on neighborhood health using both historical HOLC residential security maps and current indicators of lending discrimination. Our study filled this gap by 1) examining the legacy of historic redlining, measured via HOLC residential security maps, on current neighborhood lending practices and three key indicators of societal health (infant mortality, physical health, and mental health) (Centers for Disease Control and Prevention, 2000; Centers for Disease Control and Prevention, 2020), and 2) investigating if sustained lending disinvestment, measured via HOLC residential security maps and present-day lending discrimination, is a determinant of current neighborhood health.

Our measure of sustained lending disinvestment captures both historic and current lending discrimination. While discriminatory lending practices are widespread, practices and patterns are complex due to the highly localized nature of historical and political context. We consider sustained lending disinvestment an indicator of structural racism because of Milwaukee's hypersegregation, which has reinforced race and place-based discrimination, including the documented mechanisms of current lending discrimination (Bartlett et al., 2017; Hanson et al., 2016, p. 555; Munnell et al., 1996). Present-day neighborhood disinvestment is an extension of racially restrictive practices such as redlining and the structure of the mortgage process. In a mortgage system with fixed costs and dynamic profits, lenders are deterred from lending in communities of color that have lower incomes, smaller houses, and are located in areas with less demand (Perry et al., 2018). If mortgages are not being made, the value of homes and businesses are negatively impacted, depressing the wealth of the entire community (Shapiro et al., 2013). Racial disparities in lending, equity, and wealth are further exacerbated by the rise of high-cost loans and new lending practices that target neighborhoods of color (Steil et al., 2018).

Milwaukee is well suited to explore health effects of structural racism (Fig. 1). A recent report revealed that among the 50 largest U.S. metropolitan areas, Milwaukee ranked consistently worst or near-worst

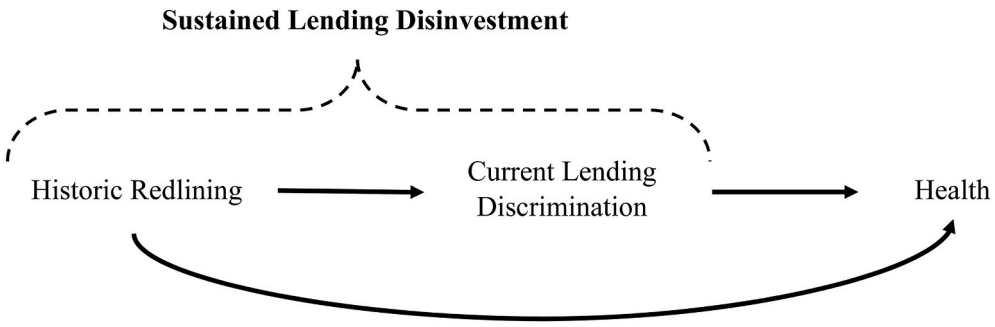

Fig. 1. Conceptual diagram guiding research questions.

across 30 indicators of racial inequality and ranked last on a composite index of Black community well-being (Levine, 2020a). Additionally, indicators of racial inequality demonstrate that Milwaukee's Black communities are worse off today than they were 40 or 50 years ago (Levine, 2020b). As Levine states, "Milwaukee, in many ways, has emerged as the epitome of a 21st century racial regime: a metropolis of entrenched segregation and racial inequality" (Levine, 2020b). Further, because of Milwaukee County's racially hypersegregated neighborhoods (Massey & Tannen, 2015), the association between sustained lending disinvestment and health at a neighborhood level can be used to shed light on racial health inequities.

Historic redlining was and is deeply harmful; we hypothesized that negative impacts of these policies and practices would be shown in associations with current lending discrimination and poor health outcomes. We hypothesized that Milwaukee census tracts subject to historic redlining would be associated with current indicators of lending discrimination and that adverse health outcomes would be highest in tracts subject to both high historic redlining and current lending discrimination.

Methods

We conducted an ecologic study to evaluate health effects of the ongoing legacy of structural racism in Milwaukee, Wisconsin using 2010 Milwaukee County census tracts as proxies for neighborhoods.

Historic redlining score

Between 1935 and 1940, HOLC, guided by its' parent organization the Federal Home Loan Bank Board, created residential security maps of over 200 major U.S. cities purportedly to inform local real estate on mortgage security and strengthen the loan industry (Hillier, 2003). The maps were color-coded to depict the level of perceived mortgage investment risk. Four hierarchical risk categories were used: green represented "A" grade which was considered the "Best" with minimal risk, blue represented "B" grade or "Still Desirable", yellow represented "C" grade or "Definitely Declining", and red "D grade" indicated "Hazardous" areas with the highest perceived risk to lenders. The HOLC maps not only included the area corresponding to each grade, but also information on housing conditions, class, and racial/ethnic composition of the neighborhood. Descriptions of red-zones, or 'redlined' neighborhoods, were commonly characterized as "undesirable" or "lower grade" populations, including Blacks, immigrants, and Jews (Hillier, 2005; Nelson et al., 2019), explicitly documenting the ways racism informed grading assessments.

We calculated a historic redlining score to assess the degree of 'redlining' within 2010 census tract boundaries. Milwaukee's HOLC residential security map, obtained from the University of Richmond's Mapping Inequality (Nelson et al., 2019), was overlaid on 2010 Milwaukee County census tracts using ArcGIS. We assigned a numerical value to each HOLC risk category as follows: 1 for "A" grade, 2 for "B" grade, 3 for "C" grade, and 4 for "D" grade. Weighted historic redlining scores for Milwaukee County census tracts were calculated from the proportion of HOLC residential security grades contained within 2010 census tract boundaries. For example, we assigned a tract graded half "A" (0.5*1) and half "B" (0.5*2) a historic redlining score of 1.5 (1.5 = 0.5*1 + 0.5*2). Continuous scores ranged from 0.5 to 4; a score of 4 corresponded to the highest degree of 'redlining' and perceived loan risk for lenders. We excluded census tracts (N = 122) with more than 50% of the area *not* assigned a HOLC grade, resulting in 174 Milwaukee County census tracts with historic redlining scores (Supplementary Table 1). We dichotomized historic redlining scores at the 25th percentile for descriptive statistics and treated historic redlining scores as continuous for regression analyses.

Current lending discrimination

We used 2018 Home Mortgage Disclosure Act (HMDA) data for Milwaukee County to measure current lending practices. HMDA, enacted by congress in 1975 and currently overseen by the Consumer Financial Protection Bureau, requires institutions to maintain, report, and disclose loan-level data (Consumer Financial Protection Bureau), Milwaukee County loan applications made during 2018 were filtered to include home purchase loans, principal residency occupancy, site built, 1 to 4-unit, and originated loans, resulting in 8380 individual loan applications (after excluding rate spread outliers informed by natural breaks in the data approximately 3 standard deviations above and below the mean) aggregated to 277 Milwaukee County census tracts.

Two HMDA variables were combined to determine current lending discrimination. First, to measure lack of access to home ownership, census tracts with fewer than five originated loans filed per 1000 family homes was used as a dichotomous indicator of low lending occurrence. Second, rate spread, a standardized indicator of loan interest rate, was used to measure high cost loans. Rate spread represents the difference between the individual loan rate that was charged and the Average Prime Offer Rate (APOR) for that day (Federal Financial Institutions Examination Council, 2020). A positive rate spread indicates that the loan's interest rate was higher than the daily average (i.e., higher rate spreads indicate higher cost loans) (Bhutta & Hizmo, 2020; Richardson & Silver, 2019). A rate spread greater than 1.5 is commonly used to indicate a high cost loan (Bhutta et al., 2017). If more than 15% (median) of originated loans in a census tract had rate spreads > 1.5, the tract was classified as having 'high cost loans.' Milwaukee County census tracts with low lending occurrence or high cost loans or both were classified as having current lending discrimination.

Lending trajectory

To assess perceived neighborhood lending risk over time, lending trajectory was created from historic redlining score and 2018 lending discrimination. Milwaukee County historic redlining scores were dichotomized at the 25th percentile (2.08) and combined with the binary

lending discrimination variable to create a four-level categorical lending trajectory: tracts with low historic redlining and no current lending discrimination (high investment), tracts with high historic redlining and no current lending discrimination (growing investment), tracts with low historic redlining and current lending discrimination (disinvested), and tracts with high historic redlining and current lending discrimination (sustained disinvestment). Sensitivity analyses were performed to explore different historic redlining cut-offs for the lending trajectory variable; the results did not change in any ways that altered the interpretation of our findings.

Health outcomes

Infant mortality rate (IMR)

We obtained the number of infant births and deaths by census tract between 2009 and 2018 from the City of Milwaukee Health Department. We calculated rolling average census tract IMRs per 1000 births from 2008 to 2019 (continuous variable) for City of Milwaukee census tracts.

Physical and mental health

We obtained data on mental and physical health from the Centers for Disease Control and Prevention's 500 Cities Project (Centers for Disease Control and Prevention, 2019). The data provided estimates of the continuous prevalence of adults aged 18 years or older who reported having poor mental or physical health, respectively, for ≥14 days in 2017 for City of Milwaukee census tracts.

Sociodemographic characteristics

For descriptive purposes, we obtained data on characteristics for each Milwaukee County census tract from the US Bureau of the Census, ACS 2014–2018 5-year estimates (U.S. Census Bureau). Continuous tract-level estimates included median age, percent of female-headed households, educational attainment, racial/ethnic composition (percent non-Hispanic/Latino white, percent non-Hispanic/Latino Black, percent Hispanic or Latino, and percent non-Hispanic/Latino other race/ethnicity) representing racialized segregation and racial differences in power and resources (Williams et al., 2019), percent of population living below the federal poverty level, median household income, and housing tenure.

Table 1
Demographic characteristics of Milwaukee County census tracts and descriptive statistics of Milwaukee County census tracts by historic redlining score and current lending disinvestment (n = 157).

	Milwaukee County Estimate N = 157	Low Historic Redlining[a] N = 39	High Historic Redlining[b] N = 118	P value	No Current Lending Discrimination[c] N = 82	Current Lending Discrimination[d] N = 75	P value
	Mean (IQR)	Mean (SD)			Mean (SD)		
2014 - 2018 5-Year American Community Survey Data							
Tract Average Median Age (years)	32.83 (7.40)	35.52 (4.81)	31.94 (5.03)	<0.01	34.00 (5.06)	31.55 (5.08)	0.01
Tract Average % of Female-Headed Households	20.71 (20.40)	15.89 (11.34)	22.30 (13.53)	0.01	13.18 (10.48)	28.93 (10.96)	<0.01
Tract Average Educational Attainment							
% 25 or older with < HS[e]	15.75 (16.92)	7.24 (6.97)	18.56 (13.52)	<0.01	10.61 (11.35)	21.36 (12.75)	<0.01
% 25 or older with = HS[f]	28.16 (16.64)	20.82 (11.59)	30.58 (10.85)	<0.01	22.27 (11.86)	34.59 (7.64)	<0.01
% 25 or older with > HS[g]	56.10 (34.41)	71.94 (17.59)	50.86 (19.75)	<0.01	67.12 (20.99)	44.05 (13.69)	<0.01
Tract Average Race/Ethnicity							
% Non Hispanic/Latino White	42.22 (68.61)	58.06 (33.88)	36.98 (32.33)	<0.01	62.90 (28.57)	19.60 (23.05)	<0.01
% Non Hispanic/Latino Black	33.82 (69.59)	29.21 (35.10)	35.34 (36.13)	0.07	15.67 (24.27)	53.66 (36.09)	<0.01
% Hispanic/Latino	17.52 (11.85)	6.24 (7.78)	21.24 (26.42)	<0.01	15.19 (21.22)	20.07 (26.80)	0.88
% Non Hispanic/Latino Other[h]	6.45 (4.89)	6.49 (4.03)	6.44 (5.31)	0.63	6.24 (3.17)	6.67 (6.47)	0.16
Tract Average Household Median Income (dollars)	46601.29 (27550.00)	66703.87 (49031.00)	39957.22 (24237.00)	<0.01	58551.94 (33535.25)	33535.25 (19233.00)	<0.01
Tract Average % Living Below the Federal Poverty Level	25.09 (23.60)	15.59 (12.33)	28.23 (14.04)	<0.01	18.55 (12.59)	32,24 (13.42)	<0.01
Tract Average Housing Tenure							
% Owner Occupied	45.64 (31.63)	58.75 (22.76)	41.30 (17.66)	<0.01	51.15 (22.14)	39.61 (16.51)	<0.01
% Renter Occupied	54.36 (31.63)	41.25 (22.25)	58.70 (17.66)	<0.01	48.85 (22.14)	60.39 (16.51)	<0.01
Home Owners' Loan Corporation 'Redlining'							
Historic Redlining Score	2.75 (1.26)	1.62 (0.38)	3.12 (0.57)	<0.01	2.57 (0.86)	2.94 (0.78)	0.01
2018 Home Mortgage Disclosure Act Data							
Tract Average Rate Spread	0.80 (0.53)	0.62 (0.34)	0.86 (0.43)	<0.01	0.54 (0.23)	1.08 (0.40)	<0.01
Tract Average Number of Originated Loans Per 1000 Family Homes	22.30 (25.25)	28.70 (14.80)	20.19 (22.28)	<0.01	31.93 (22.98)	11.78 (11.54)	<0.01

Abbreviations IQR, Interquartile Range; SD, Standard Deviation.

[a] Low Historic Redlining- Historic redlining score <2.08 (dichotomized at the 25th percentile).

[b] High Historic Redlining- Historic redlining score ≥2.08 (dichotomized at the 25th percentile).

[c] No Current Lending Discrimination- Census tracts ***without*** low lending occurrence (≥5 originated loans filed per 1000 family homes) and ***without*** 'high cost loans' (<15% of the originated loans in the tract had rate spreads > 1.5).

[d] Current Lending Discrimination- Census tracts ***with either*** low lending occurrence (<5 originated loans filed per 1000 family homes) or 'high cost loans' (>15% of the originated loans in the tract had rate spreads > 1.5).

[e] Less than high school diploma/equivalent- Includes no schooling, nursery school, kindergarten, and grade 1–12 but no high school diploma.

[f] High school diploma/equivalent- Includes regular high school diploma and GED/alternative credential.

[g] Some college or more- Includes some college less than 1 year, some college 1 or more years no degree, Associate's degree, Bachelor's degree, Master's degree, Professional school degree, and Doctorate degree.

[h] Other Race/Ethnicity- Include non-Hispanic/Latino American Indian and Alaska Native, non-Hispanic/Latino Asian, non-Hispanic/Latino Native Hawaiian and other Pacific Islander, non-Hispanic/Latino other race, and non-Hispanic/Latino two or more races.

Statistical analysis

We excluded tracts without HOLC historic redlining and HMDA lending data, resulting in an analytic sample of 157 Milwaukee County census tracts. Of these, health data were only available for tracts within the City of Milwaukee (N = 123). All analyses were conducted in SAS 9.4 (SAS Institute, Inc., Cary, NC). We evaluated differences in the distribution of characteristics with T-tests, Wilcoxon two-sample tests, and Pearson correlations for continuous variables and chi-square tests for categorical variables. A two-sided p-value of <0.05 was considered statistically significant. We used logistic regression to examine the association between historic redlining score and current lending discrimination. We used simple linear regression to estimate the association between 1) historic redlining score and each health outcome and 2) lending trajectory and each health outcome. We considered tract sociodemographic characteristics mediators of the associations examined and thus were not controlled for in analyses.

Results

Socioeconomic and racial characteristics of Milwaukee County census tracts varied by historic redlining and current lending discrimination (Table 1). Tracts with high historic redlining and tracts with current lending discrimination had, on average, a lower percent of non-Hispanic/Latino white residents, higher percent of Hispanic/Latino and non-Hispanic/Latino Black residents, lower median household income, higher percent of the population living below poverty, and lower percent of owner-occupied housing compared to tracts with low historic redlining and tracts with no current lending discrimination (Table 1). Tracts with high historic redlining and current lending discrimination had, on average, lower educational attainment, a younger tract average median age, and a higher percent of female-headed households compared to tracts with low historic redlining and no current lending discrimination. For example, tracts with low historic redlining had a tract average poverty rate of 15.59% compared to 28.23% among tracts with high historic redlining. Tracts with no current lending discrimination had a tract average poverty rate of 18.55% compared to 32.24% among tracts with current lending discrimination. Tracts with high historic redlining had higher tract average rate spreads and fewer originated loans on average than tracts with low historic redlining (0.86 and 0.62 tract average rate spread; 29.19 and 28.70 originated loans per 1000 family homes, respectively), while tracts with current lending discrimination had higher historic redlining scores than tracts without current lending discrimination (2.94 and 2.57, respectively; Table 1).

Historic redlining was associated with greater current lending discrimination (either low lending occurrence or high cost loans); a one-unit increase in historic redlining score resulted in 73% higher odds of current lending discrimination in Milwaukee County census tracts (95% Confidence Interval (CI): 1.16, 2.58). This finding translates to a 64.40% predicted probability of current lending discrimination for tracts with high historic redlining (score of 4) compared to a 25.80% for tracts with low historic redlining (score of 1) (Fig. 2).

Prevalence of poor physical and mental health and IMR were correlated with socioeconomic and race/ethnic composition of neighborhoods such that higher poverty, lower household median income, lower educational attainment, higher percent renter occupied housing, lower percent non-Hispanic white residents, and higher percent non-Hispanic Black residents were found in tracts with worse health outcomes (Supplementary Table 2). Higher historic redlining score correlated with higher poor physical ($r = 0.248$; $P = 0.01$) and mental health ($r = 0.290$; $P < 0.01$), and higher prevalence of all three poor health outcomes were in tracts with higher tract average rate spread ($r = 0.408$–0.553; $P < 0.01$) and lower loan occurrence ($r = -0.71$–0.41; $P < 0.01$) (Supplementary Table 2). Higher historic redlining score was associated with increased tract prevalence of poor physical ($\beta = 1.34$, 95% CI: 0.40, 2.28) and poor mental health ($\beta = 1.26$, 95% CI: 0.51, 2.01) (Fig. 3), but not with IMR ($\beta = -0.48$, 95% CI: −2.12, 1.15).

Fig. 4 displays the Milwaukee HOLC map and the spatial distribution in Milwaukee County of historic redlining scores and lending trajectory variable. Tracts with sustained disinvestment were predominantly located on the City's north and south side, while tracts with high investment were predominantly located on the City's East (bordering Lake Michigan) and West side (Fig. 4C). There was a graded association between lending trajectory and health: tracts with high sustained disinvestment had worse physical and mental health than tracts with high investment (poor physical health: $\beta = 5.33$, 95% CI: 3.05, 7.61; poor

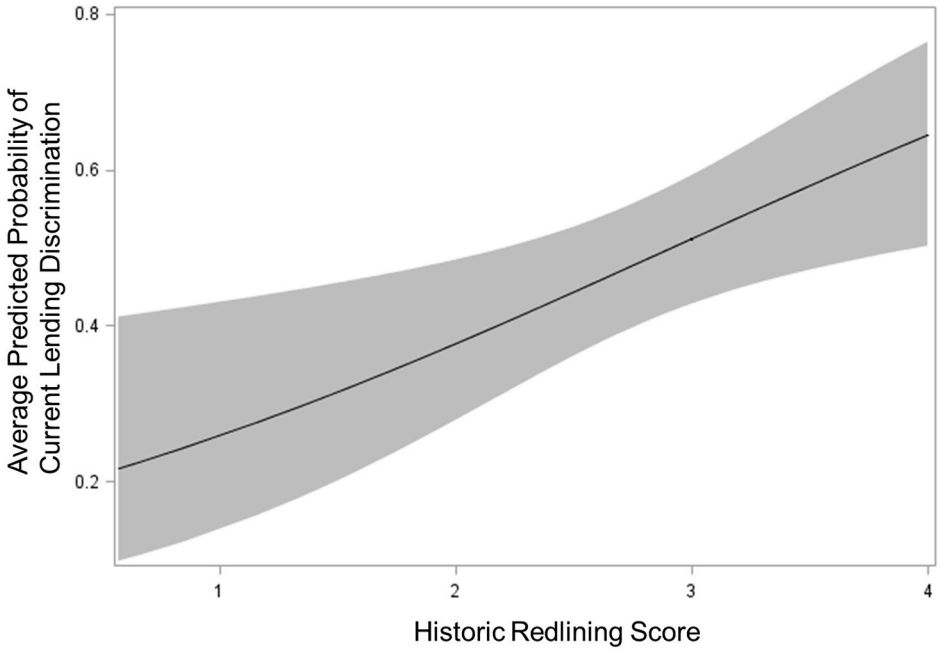

Fig. 2. Average predicted probability and 95% confidence interval of current lending discrimination by historic redlining score in Milwaukee County census tracts (N = 157).

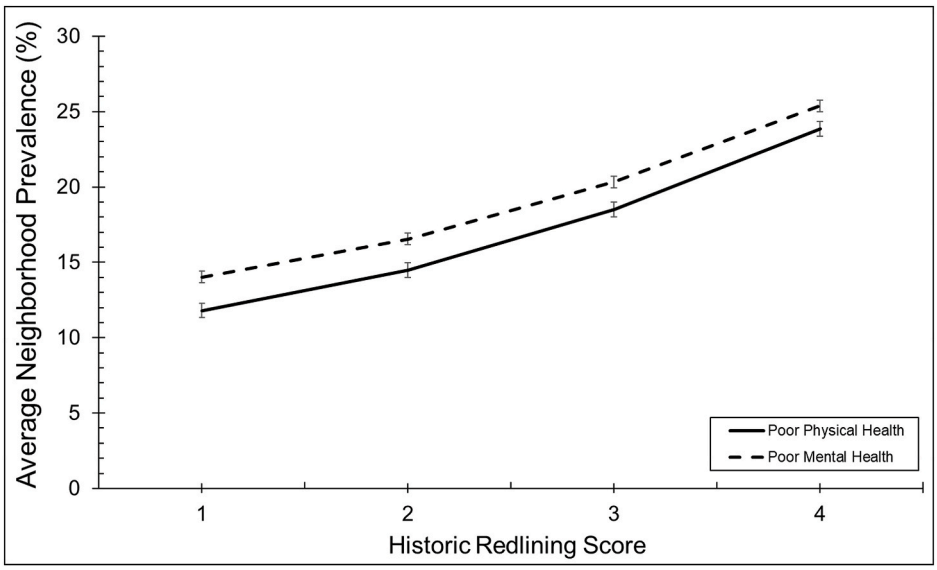

Fig. 3. Linear regression results of historic redlining score and prevalence of poor physical health and prevalence of poor mental health rate in Milwaukee City census tracts (n = 123).

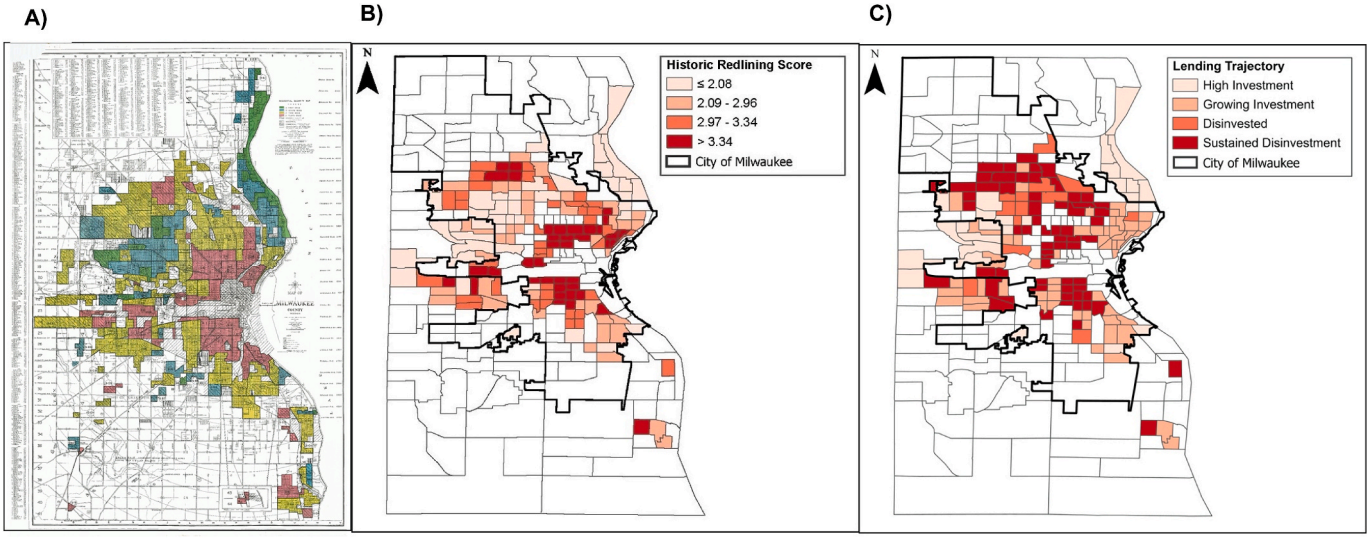

Fig. 4. A) Milwaukee County HOLC residential security map obtained from the University of Richmond's Mapping Inequality. B) Milwaukee County historic redlining score (n = 157) calculated for 2010 Milwaukee County census tracts from the proportion of Home Owners' Loan Corporation residential security grades contained within current census tract boundaries. Continuous scores ranged from 0 to 4, with higher scores corresponding to more 'redlining'. Census tracts with more than 50% of the area not assigned a HOLC grade were excluded. Quartile classification was utilized based on the geographic distribution of the data at the census tract level. C) Milwaukee County lending trajectory (n = 157). Census tract historic redlining score was dichotomized at the 25th percentile and combined with the binary lending discrimination variable (data obtained from 2018 Home Mortgage Disclosure Act Data) to create a 4-level categorical lending trajectory: tracts with low historic redlining and no current lending discrimination (high investment), high historic redlining and no current lending discrimination (growing investment), low historic redlining and current lending discrimination (disinvested), and high historic redlining and current lending discrimination (sustained disinvestment). Of the 157 Milwaukee County census tracts, 123 tracts reside within the City of Milwaukee boundaries. Service layer credits to Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community.

mental health: β = 4.32, 95% CI: 2.44, 6.20). IMR was highest in 'disinvested' tracts (β = 5.87, 95% CI: 0.52, 11.22) (Fig. 5).

In an exploratory analysis, we created a latent variable representing current tract level socioeconomic status from indicators including household median income, percent low education, percent below the poverty line, and percent non-white residents and evaluated this variable as a mediator of the association between historic redlining and neighborhood health outcomes. As expected, the associations observed were almost entirely mediated by these proximate contextual factors (Supplementary Table 3). The association between historic redlining and physical health was 85% mediated by current neighborhood socioeconomic indicators, and the association between historic redlining and mental health was 87% mediated by current neighborhood socioeconomic indicators.

Discussion

To our knowledge, this is the first empirical study to use both historical HOLC residential security maps and current measures of lending discrimination to examine health effects of structural racism. Our

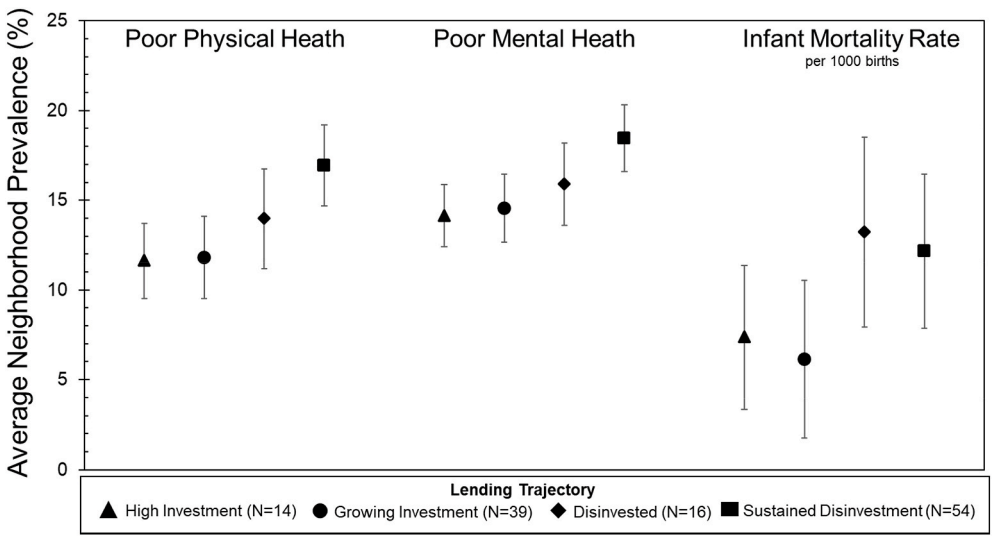

Fig. 5. Association of lending trajectory and tract average prevalence of poor physical health, prevalence of poor mental health, and infant mortality rate per 1000 persons in Milwaukee City census tracts (n = 123). Tracts were categorized as follows: tracts with low historic redlining and no current lending discrimination (high investment), high historic redlining and no current lending discrimination (growing investment), low historic redlining and current lending discrimination (disinvested), and high historic redlining and current lending discrimination (sustained disinvestment).

findings illustrate the ongoing legacy of government sponsored historic redlining. We found that historic redlining alone was associated with current lending discrimination in Milwaukee County and with poor mental and physical health in the City. Moreover, the observed positive graded association between lending trajectory and health suggests that structural racism, as manifested in both historic and current forms of lending disinvestment, predicts poor health in Milwaukee's hypersegregated neighborhoods.

Our work is consistent with growing evidence showing that structural racism in the housing market, and the legacy of HOLC residential security maps in particular, is associated with current adverse health outcomes. We add to this literature by showing historic redlining was associated with poor self-reported mental and physical health. Aligning with the only other study to assess HOLC 'redlining' in relation to current housing instability (measured via post Great Recession foreclosure rates) and health, (McClure et al., 2019), our findings suggests that redlining may act as a historical driver of current neighborhood housing characteristics and health (McClure et al., 2019).

Our study adds to limited literature examining health effects of racial discrimination in current home mortgage lending (Beyer et al., 2016; Beyer et al., 2019; Mendez et al., 2011; Zhou et al., 2017). Using HMDA data to evaluate the ways structural racism manifests in mortgage lending, Beyer et al. (Beyer et al., 2016) utilized two indices of home mortgage denial, mortgage denials by applicants' race and mortgage denials by the neighborhood in which the applicant was seeking to reside. Mortgage denials by neighborhood have been evaluated in relation to racial cancer inequities in Milwaukee and surrounding metropolitan areas with mixed results (Beyer et al., 2016; Beyer et al., 2019). We build on this research, capturing additional dimensions of racialized lending discrimination including neighborhood lending occurrence and high cost loans in Milwaukee's hypersegregated neighborhoods.

This study has limitations to consider. First, health data were limited to City of Milwaukee tracts and we only included tracts in analyses if more than 50% of the tract was assigned a residential security grade. Both decisions excluded predominantly white, healthier, high income tracts that were developed post-HOLC redlining (Supplementary Table 1) and may underestimate the associations. Second, we constructed current lending discrimination from 2018 HMDA data, yet mental and physical health data were from 2017 and rolling average IMRs were from 2008 to 2019. Still, no major shifts in health prevalence occurred during this time frame and trends in housing discrimination are not unique to 2018; thus, we would expect similar results if our analyses were repeated with HMDA and health data from other proximal years. Third, our sustained lending disinvestment measure used two time points; future studies should use repeated measures to capture persistent trends in disinvestment over time. Noteworthy, most previous studies involving HOLC redlining were ecological, as was ours, with few multi-level analyses (Krieger, Van Wye, et al., 2020; Krieger, Wright, et al., 2020; McClure et al., 2019). Our study was not subject to ecologic bias because structural racism is inherently a group-level variable and our inferences were at a neighborhood level (Diez Roux et al., 2009). Future work should assess effects of structural racism on both neighborhood-level and individual-level health outcomes to directly measure health inequities. We were unable to characterize trends in macro segregation and there may be other forces not captured in our study that contribute to our results (e.g., changes to Milwaukee's economy, lending policies, community-level racist norms, etc.), all of which warrant future research (Lichter et al., 2015; Osypuk & Acevedo-Garcia, 2010). Finally, while sociodemographic patterns are a potential path by which redlining may influence current neighborhood health, there are many potential mediating pathways, all of which deserve intense study. The mediation analysis we presented was exploratory as it was not the focus of this study. A study dedicated to understanding the multiple mediating pathways and longitudinal socioeconomic changes over time connecting redlining and neighborhood health is needed.

This study also has many strengths. Our continuous historic redlining score allowed us to capture the degree to which a tract was subject to redlining. Only one other study, to our knowledge, has used a weighted continuous score to assess redlining (Crossney & Bartelt, 2005); our method used different exclusion criteria and is the first to examine a continuous historic redlining score in relation to health. Further, we generated a novel measure of lending trajectory to evaluate health legacies of structural racism in the housing market. This measure captured time and context-specific dimensions of structural racism in Milwaukee by encompassing both historic and current lending discrimination (Gee & Ford, 2011).

As illustrated in the HOLC residential security map neighborhood descriptions (Nelson et al., 2019), racialization has changed over time while still ascribing value based on proximity to whiteness (Bailey et al., 2017). The Milwaukee County HOLC residential security map was created before the first major wave of Black migration into Milwaukee neighborhoods in the 1950s (commonly referenced as the "Late Great Migration") (Miner, 2013). As outlined in Milwaukee's HOLC residential security map, prior to 1970, most of Milwaukee's Black residents were restricted to living just northwest of downtown in Bronzeville (Slattery & Doremus, 2019). The HOLC map outlined other 'redlined'

neighborhoods in Milwaukee that, at that time, were predominantly inhabited by immigrants and Jews. However, as Milwaukee's racialization and migration patterns changed, subsequent anti-Black disinvestment in the decades after HOLC residential security maps shifted with Black migration patterns. During the 1950s and 60s policy decisions regarding the creation and placement of the Interstate-43 expressway and urban renewal projects led to the demolition of Walnut Street (Milwaukee's Black business district) and thousands of homes. Bronzeville, Milwaukee's historic Black neighborhood, was destroyed by the early 1970s (Slattery & Doremus, 2019). Concurrent with Milwaukee's historic open housing marches that lasted 200 consecutive days and the 1968 open housing ordinance prohibiting housing discrimination, Milwaukee's Black population moved further into Milwaukee's northwestern neighborhoods (Jewish Museum Milwaukee, 2018).

The history of racialization, Black migration, and anti-Black racism in Milwaukee provides context to understanding what is captured in our housing disinvestment measures and our results. First, our lending trajectory variable appears to align with these historical patterns of migration and disinvestment. 'Disinvested' census tracts on Milwaukee's northwest side represent neighborhoods that were not explicitly redlined in the 1930s but experienced anti-Black disinvestment in the following decades. Second, IMR was not associated with historic redlining alone and 'disinvested' tracts had the highest average IMR. The 'disinvested' tracts with the highest IMRs are predominantly Black neighborhoods in the City's northwest side (Supplementary Figure 1).

Importantly, our infant mortality results do not suggest that redlining is not harmful; rather, our findings show that understanding local historical context elucidates how racism has manifested over time in Milwaukee neighborhoods to impact neighborhood (dis)investment and health. Discrimination is unjust even if it does not affect all outcomes, and, as our results suggest, variations in findings may elucidate pathways, patterns, and potential interventions. We found infant mortality to be highest in predominantly Black tracts that experienced disinvestment subsequent to HOLC redlining and lowest in predominantly white tracts that experienced investment subsequent to HOLC redlining. These results have important implications locally. Infant mortality is a key indicator of population level health and Milwaukee has alarmingly high infant mortality rates driven by large racial inequities in these rates. According to 2015–2017 data reported by the City of Milwaukee, the infant mortality rate among non-Hispanic Blacks was three times higher than that of non-Hispanic whites (City of Milwaukee Health Department, 2018). Our findings suggest that there are points for potential intervention, yet because racism is likely still impacting neighborhood patterns of investment and health, interventions designed to target discriminatory lending and investment must be directed for and with Milwaukee's Black communities.

We explore the legacy of housing discrimination in Milwaukee, Wisconsin, however, racist housing policies are not exclusive to Milwaukee. National studies have shown the legacy of HOLC redlining on current neighborhood-level socio-economic and health outcomes in cities across the country (Hoffman et al., 2020; Namin et al., 2020; Richardson et al., 2020). This study utilizes Milwaukee's story to elucidate tools to evaluate the health effects of sustained housing disinvestment over time. However, racial inequality plagues hypersegregated cities across the United States, each of which has unique but parallel historical patterns of racialized disinvestment.

While racism permeates racialized societies, the mechanisms of how racism operates has changed over time (Ford & Airhihenbuwa, 2010). U. S. legalized racial discrimination was banned in the 1960s, yet a multitude of policies and practices have continued to reinforce structured racial inequality (Bailey et al., 2017). Structural racism continues to manifest today in racial inequities in housing, wealth accumulation, employment, criminal justice, poverty, education, and health (Churchwell et al., 2020). The ways structural racism ever-evolves to recreate racial inequality must inform how we measure and study structural racism as well as how we dismantle and redress it (Bailey et al., 2017).

HOLC residential security maps are a manifestation of structural racism and represent only one tool for gaining insight into historical risk assessment practices. We endorse equity focused policies that seek to dismantle and repair the legacies of structural racism in the housing market by redressing the ways racism, past and present, give rise to both racial hierarchies and health inequities. Racial wealth gaps hinder Black Americans' ability to weather adversity; thus, policies must close the racial wealth gap and combat recurring structural sources of racial inequities. Redistributive efforts should directly invest in Black communities that were denied opportunities to build wealth through government sponsored policies and practices (Rothstein, 2017). Proposed options include housing subsidies for neighborhoods historically denied mortgages, reparations that provide direct cash payments, full and free access to quality education, and a guaranteed minimum livable income for Black Americans (Jones, 2020; Movement For Black Lives, 2021; Rothstein, 2017). However, as our findings support, direct investments must be implemented simultaneously with stringent enforcement of civil rights laws and institutional lending regulations. If not done concurrently, racism embedded in lending institutions can actively maintain racial inequities. Further, although our lending trajectory results do provide some support of health improvements associated with investment subsequent to historic redlining, many of the healthier 'growing investment' tracts are predominantly white. Thus, because racism is likely still shaping patterns of strategic investment, we support policies that directly invest in communities of color. Policies that construct and preserve affordable housing (Lubell, 2016) and encourage equitable development through increased investment without displacement are necessary (Hyra, 2016). Historically, interventions designed to reduce racial housing discrimination have had negative consequences, thus, inclusion of community members in redevelopment efforts is needed. Moreover, efforts to combat racism within the housing market alone are insufficient (Bailey et al., 2017). Eliminating structural racism requires intersectoral action that targets both formal and informal practices, thereby challenging the ways racism is entrenched in America's social fabric.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2021.100793.

Author contributions

All authors have participated in preparing the manuscript and have reviewed and approved its final, submitted version. Helen Meier and Emily Lynch conceived the study. Emily Lynch conducted the data analyses and drafted the manuscript. Sarah Laurent and Emily Lynch created the historic redlining score and Sarah Laurent contributed to the data analysis. All authors contributed to data interpretation and critically revised the manuscript for important intellectual content. This manuscript has not been submitted or accepted elsewhere.

Ethics statement

The authors report no conflict of interest.

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