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Historical Redlining and the Epidemiology of Present-Day Firearm Violence in the United States: A Multi-City Analysis

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Abstract

Firearm violence is a major cause of morbidity, mortality, and racial health disparities in the United States. Previous studies have identified associations between historically racist housing discrimination (i.e., redlining practices) and firearm violence; however, these studies generally have been limited to a single city and have yet to provide sufficient evidence through which to determine the extent and dynamics of the impact of this relationship across the country. The aim of our study was (1) to estimate the association of historical redlining on both violent and firearm death across the country in nested models; and (2) to examine spatial non-stationarity to determine whether the impact of historical redlining on violent and firearm death was the same across the U.S. We used multilevel Bayesian conditional autoregressive Poisson models to determine the relationship between redlining as illustrated through Home Owners' Loan Corporation maps and 2019 violent and firearm deaths at the ZIP code-level nested within 21 cities across the U.S. We found that at the ZIP code level, there was a dose-responsive relationship between HOLC grading and the incidence of present-day firearm deaths. In general, redlined ZIP codes had higher relative incidence of firearm deaths. Associations were not stable across cities. For example, associations were relatively stronger in Baltimore, MD and weaker in Los Angeles, CA. This research reinforces the findings of previous studies examining the impact of redlining on firearm death across the extent of the entire country in 21 cities and claim that HOLC grades are associated with present-day violence.

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Study Setting: United States

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Firearm violence is a leading cause of morbidity and mortality in the United States (US). In 2019, 39,707 people were killed with a firearm with rates highest in males, those between the ages of 15 and 34 years, and among Black, American Indian/Alaskan Native, and Hispanic populations.[1] Differences in racial and ethnic exposure to firearm violence compound existing health disparities (i.e., preventable differences in the burden of disease that are experienced by socially disadvantaged populations)[2] in physical injuries and long-term mental and physical health.[3] Recently, firearm injuries have surpassed motor vehicle crashes as the most common cause of injury death in the US.[4] Addressing firearm violence through the social and environmental contexts that increase the firearm injury risks remains imperative in order to improve the safety and well-being of individuals and communities and to reduce racial health disparities.

Geographic concentration of firearm incidents suggests that neighborhood-level factors contribute to the epidemiology of violence (i.e., assault, homicide, rape and robbery).[5–7] For example, neighborhood poverty, social disadvantage, and residential instability are all associated with violence.[8,9] Following evidence from studies that identify a relationship between neighborhood disadvantage and violence,[10] quasi-experimental studies and randomized controlled trials of place-based interventions (i.e., blight remediation and vacant house demolition) have proven effective in reducing violence overall.[11] However, in order for neighborhood-level interventions to be sustainable for the communities in which they are implemented, we must accompany the focus on the environmental contexts that produce "hot spots" for firearm violence[12] with a historical perspective, that incorporates the history of structural racism in the US. This perspective can provide insight into both the creation and perpetuation of policies and practices[13–15] that produce the context in which hot spots emerge and persist.[12]

Using the definition by Bailey et al., structural racism is "the totality of ways in which societies foster racial discrimination, through mutually reinforcing inequitable systems (in housing, education, employment, earnings, benefits, credit, media, health care, criminal justice, etc.) that in turn reinforce discriminatory beliefs, values, and distribution of resources, which together affect the risk of adverse health outcomes".[16] It is imperative to incorporate a historical lens that acknowledges forces of structural racism when examining public health problems with distinct racialized dynamics, like the morbidity and mortality associated with interpersonal firearm violence. This allows us to examine the extent to which historical and sustained forces of social and economic marginalization impact violence and exposure to violence which can inform interventions in policy and public health practice. Without a historical lens, present-day disparities are biasedly viewed as "natural" or "the fault of" people living in communities with high crime and violence.[13]

Attention to the structural racism, whether in historic or contemporary forms, shifts the focus from interventions solely framed to reduce violence and racial disparities at an individual level to the institutions and structures that have propagated health disparities in violence and injury throughout history.[14,17] More complex and nuanced illustrations of the historical antecedents of contemporary public health interests also provide a richer and more contextualized understanding of, in this case, the lived experiences of populations and communities residing in geographic hot spots of firearm violence.[12,13] Examining the relationship between structural racism and present-day violence is imperative to identifying fundamental causes of health disparities that have persisted over time.

The impact of "redlining" has increasingly become a focus for empirical examinations of the ways in which structural racism has shaped health disparities over time. The term refers to discriminatory mortgage lending practices under the Home Owners' Loan Corporation (HOLC) established as part of Roosevelt's New Deal policies in the 1930s. The HOLC was commissioned specifically to slow the rate of foreclosures occurring in during the Great Depression to begin to stabilize US urban centers.[18] The HOLC evaluated features of city geography, development, and demographic composition and determined, and then mapped out the relative 'risk' of federally-backed mortgage investment by neighborhoods over a period from 1934 to 1940 for 239 US cities.[19] A Grade A or green color was assigned to areas deemed ideal for investment (i.e., affluent home buyers and plentiful space for development). A Grade B or blue color represented areas considered well-developed and stable. A Grade C or yellow color characterized areas with evidence of decline and influx of what was termed a "low-grade population".[20] Finally, a Grade D or red color was reserved for areas with older housing stock,[19] poorer households, and an "undesirable population" of most Black, immigrant, and Jewish people (hence: "redlining").[20] In the aftermath of the HOLC and risk-mapping, more affluent and White areas maintained the benefits associated with homeownership and urban investment, while low-income most often comprised of communities of color and immigrants were functionally prohibited loans.[17]

There is a growing body of evidence that establishes a significant relationship between the racist lending practices of the HOLC and health disparities in the US many decades later. These disparities include rates of asthma,[21] preterm births,[22] self-rated health,[23] mental health,[24] cancer,[25,26] and chronic disease.[27] There is supportive evidence that associates environmental changes with historic redlining, such as alcohol outlet clustering,[28] diminished greenspace availability,[29] and urban heat.[30]

Several recent studies identify associations between HOLC gradations and present-day incidence of firearm violence.[31–33] The social epidemiology literature is replete with analogous examples of upstream policies that shape downstream population health over many decades, including by contributing to socio-economic disparities.[34–38] Despite the increasing abundance of studies that identify statistical associations between HOLC map depictions of city regions deemed "hazardous" or "risky"[39] and present-day firearm violence, important limitations for establishing a causal pathway remain. Existing evidence suggests that historic redlining altered neighborhood social and environmental conditions, such as decreasing rates of home ownership, decreasing educational attainment, and increasing segregation of Black communities, which are all associated with a higher incidence of firearm violence.[33] Further, Hillier discusses, in a study of redlining in the city of Philadelphia, that lenders avoided certain areas deemed "high risk" even before the creation of the HOLC maps,[20] implying that the maps may have been influenced by different common causes of both creation of HOLC maps and most likely violent death and firearm death. Although redlining is generally attributed to the HOLC, there is evidence that HOLC was following already-established racist practices of the real estate and mortgage system, and although HOLC may not have originally created the redlining practices, it did provide an explicit illustration of the racist economic exclusion practices existing at the time of the creation of the maps[40] with the intention to “reinforce not challenge existing patterns of racial segregation.”[41] Because the HOLC maps were already capturing existing place- and population-based lending practices that already existed and perpetuated disadvantage at the time[42] and the pathway from redlining to present-day firearm violence is separated by some nine decades, controlling for social and economic conditions that were present at the time the HOLC maps were produced is unlikely to fully account for the entirety of confounding forces through available historic census data. Without a statistical or methodological solution for this problem, it is incumbent for researchers to address any plausible confounders as best as possible.

Notwithstanding problems related to treatment implementation and unmeasured confounding, researchers are beginning to overcome some major limitations when assessing associations between redlining and public health outcomes. For example, Nardone et al. reduced the likelihood that positivity violations (i.e., non-zero probability of redlined areas not being redlined) could bias estimates by comparing areas with Grade A to Grade B, Grade B to Grade C, and so on.[29] Another common limitation is that extant studies examining the relationship between redlining and firearm violence have assessed isolated cities; that is, examination in one city at a time without consideration of proximity to other cities. However, certain modeling techniques allow us to circumvent the fact that spatial units near each other are more likely to be similar than those further apart, and the likely the correlation of units that are close to each other, and explore group-level and individual-level predictors (i.e., larger units and nested units).[43,44] With carefully considered multilevel models we are able to examine the relationship between redlining on violence; it remains imperative to do so beyond a few cities and over the full extent of the US.

Studies of geographically structured data, including health data, point to a major problem that could affect research relating redlining to violent death and firearm death—*spatial non-stationarity.*[45] Spatial non-stationarity refers to moderation of the relationship across geographic locations, such that associations might be stronger in some locations, weaker in others, and perhaps even reversed elsewhere. Applied to the current associations of interest, to better understand how the HOLC mapping practices lead to increased rates of violent death and firearm death, it is important to understand if the impact of redlining was uniform across the extent of the US.

Aims

To assess associations while accounting for common problems that can affect analyses of spatially structured data, we look to go beyond previous studies of this association examining a single city and examine the relationship between redlining and violence across the extent of the US. The aim of this study was (1) to estimate the association of historical redlining on both violent and firearm death across the US in nested models; and (2) to examine spatial non-stationarity to determine whether the impact of historical redlining on violent and firearm death was the same for different contexts in the US.

METHODS

Ethical Compliance

This study was granted approval from the Columbia University Institutional Review Board.

Study Design

This cross-sectional ecological study related area-level redlining measures to aggregate measures of present-day violent and firearm deaths within US ZIP codes. Data capturing historical redlining were digitized maps from the HOLC assessment, accessed through the *Mapping Inequality* project.[39] Historical demographic characteristics were accessed through the National Historical Geographic Information System.[46] Violent death was measured using records from the National Violent Death Reporting System (NVDRS) for 2019, accessed by restricted use agreement through the Centers for Disease Control and Prevention.[47] The units of analysis were 2019 ZIP codes, and data were structured as ZIP codes (level 1 units) nested within cities (level 2 units). Included ZIP codes were those for which data were available for historical redlining, historical demographic composition, present-day violent and firearm death, and which had ≥ 10 ZIP codes per city. The final sample yielded 576 ZIP codes nested in 21 cities.

Historical Redlining

Digitized HOLC maps are files structured for use in a geographic information system, wherein the 1935–1940 assessments are represented as layers in a polygon shapefile. These polygons can be visualized using a choropleth color scheme that corresponds with the original grades—Grade A areas shown as green, Grade B areas shown as blue, Grade C areas shown as yellow, and Grade D areas shown as red. For example, Figure 1 shows the original and digitized versions of HOLC maps from Los Angeles. The *Mapping Inequality* project houses a repository of digitized HOLC maps for 209 US cities.

The main exposure of interest was the proportion of land area in each ZIP code that had each HOLC grade. We overlaid the polygon shapefile representing the HOLC assessments and a polygon shapefile representing the 2019 boundaries for the included ZIP codes within a common geographic reference system (ESPG: 4269, NAD83). We computed the geometric intersection between these two polygons to calculate five variables measuring the proportion of land area within each ZIP code: Grade A, Grade B, Grade C, Grade D, or had no HOLC grade. The range of possible values for these continuous variables was between 0 (indicating no land area within the ZIP code received that grade) and 1 (indicating all land area within the ZIP code received that grade). The sum of the values for the five variables within each ZIP code was 1. This method was also conducted in the analysis by Jacoby et al.[32]

Violent and Firearm Death

The outcome of interest was counts of violent and firearm deaths in 2019 as captured in the NVDRS. These data are extracted from death certificates, coroner or medical examiner's reports, and police reports by trained abstractors in participating locations. The year reported is the calendar year in which the victim died for an incident involving a single death or the year the first victim died in an incident involving multiple deaths. The NVDRS has been operational since 2002. Each year up until 2019, a different number of states (and counties) contribute to the database. By 2019, all 50 states, the District of Columbia, and Puerto Rico contributed to the system.[47–50] Available data are victim demographic characteristics, weapon types, suspects, victim–suspect relationships, location, precipitating circumstances, and geographic location. The NVDRS categorizes a death as a violent death if it was a "death that result[ed] from the intentional use of physical force or power, threated or actual, against oneself, another person, or a group or community."[51] The smallest unit for which NVDRS provides location information is on the ZIP code level. The abstractor assigns a "type of death" code to the case and writes two brief narratives on each incident to summarize the coroner or medical examiner report and the police report. We accessed these data at the individual level and then calculated counts of violent deaths in 2019 per included ZIP code. Types of weapons listed included drowning, falls, poisoning, motor vehicles, firearms, etc. Using the information on primary weapon type, we also calculated counts of firearm deaths in 2019 per included ZIP code. We excluded states with incomplete case reporting, according to the NVDRS designation.

Historical Demographic Characteristics

Digitized data for the decennial census data are available through the National Historical Geographic Information System from 1790 to 2020. We conceptualized the historical demographic composition as a potential confounder for the relationship between HOLC grades and present-day violent and firearm death because HOLC assessments were dependent on resident characteristics. Isolating the effect of historical redlining on present-day health outcomes requires conditioning—statistically or methodologically—on this key confounder. Data for the 1930 census is available at the tract-level in digitized form; however, due to the greater number of demographic characteristics available for 1940 census data and given that demographic composition was not likely to change greatly in three years in response to the HOLC maps, we elected to use the 1940 census data. Our decision to control for variables in 1940 census data near to the time in which HOLC maps were created was to acknowledge a handful, albeit limited, potential confounders. This method has been used in previous analyses of redlining.[29,32]

We calculated measures of historical demographic composition within US ZIP codes by overlaying the 2019 ZIP code boundaries using the publicly available ZCTA shapefiles from the Census and the 1940 census tracts. Boundaries for these files were misaligned, which is a common problem for spatial epidemiologic studies and many authors have proposed solutions for use within conventional analytic frameworks.[52–57] Given that historical demographic composition was neither the primary exposure nor outcome of interest, we selected an accessible solution that is commonly used within the geospatial sciences.[58] We calculated the centroid for the 1940 census tracts, then spatially joined these points to the ZIP code polygons. Values for the census tracts were assigned to the ZIP codes as measures of historical demographic composition for that location.

We calculated two main variables using the 1940 census data—a composite measure of concentrated disadvantage and the index of concentration at the extremes (ICE) for race/ethnicity. Following Jacoby et al.[32], we extracted variables that are available in historical census data that could theoretically proxy for concentrated disadvantage in 1940. Available variables were the proportion of: residents aged ≥ 25 years without a high school certificate, dwellings that were tenant occupied, dwellings that did not have transistor radio, dwellings that did not have a mechanical refrigerator, dwellings that did not have central heating, and dwellings with ≥ 1 person per room. The sum of these six variables yielded a measure of concentrated disadvantage with values between 0 (advantaged) to 1 (disadvantaged) (Table 1).

The ICE was first proposed by Massey[59] and has been used increasingly in spatial epidemiologic studies to capture structural racism through the examination of social polarizations of those privileged and deprived communities in one given spatial unit.[60–62] An ICE value of 1 means the entire population of a given area belongs to the most privileged group, specifically White in this study, and a value of −1 means that all residents are in the most deprived group, specifically Black in this study.[59,62] The ICE for race/ethnicity is important to capture processes that produce health disparities.[62] For the purposes of this study, in order to create an ICE for race/ethnicity score using only 1940s variables due to the temporality of the relationship between historical demographic characteristics, historical redlining, and modern-day violence, we used total population of the census tract, total White population, and total Black population.[62–64] Based on literature describing racial hierarchy in the 1940s, we chose to compare Black and White populations:[17]

$$ICE_{1940} = \frac{total\ White - total\ Black}{total\ Population}$$

Statistical Analysis

We used hierarchical Bayesian conditional autoregressive Poisson models to relate present-day violent and firearm death to HOLC grades while controlling for historical demographic composition. Analyses were implemented in R-INLA, which calculates the Integrated Network Laplace Approximation of a fully Bayesian model.[57,65,66] We used this computationally efficient approach to approximate the results of a Besag-York-Mollie models with a conditional autoregressive random effect that controls for spatial dependencies.[65]

First, we related counts of violent and firearm deaths in each HOLC grade. Clustering of ZIP codes in cities was controlled statistically using random intercepts for cities. Model 1a was a crude model, including only the local HOLC grades. Model 1b added the two measures of historical demographic composition (concentrated disadvantage and the ICE).

Second, to consider possible non-stationarity (i.e., different association between cities), we assessed varying associations between local HOLC grades and violent and firearm deaths in a series of additional analyses. Informed by Nardone et al.,[29] we combined the Grade C and Grade D variables into a single variable, such that the reference group was Grade A, Grade B, and no Grade.[29] In model 2, we included dummy variables for each of the 21 included cities, allowing assessment of the difference between parallel slopes for HOLC grades, and added cross-product term between Grade C/D and cities. The city with the greatest ZIP code average population size, Chicago, served as the reference category. We interpreted the parameter estimate for the cross-product term as the city-specific difference in the association between Grade C/D zoning and the incidence of violent and firearm death in this study.

Sensitivity Analysis

We conducted sensitivity analyses for the years 2017 and 2018. The years were not aggregated due to the difference in case reporting across the United States. Using hierarchical Bayesian conditional autoregressive Poisson models, we relate present-day violent and firearm death to HOLC grades, while controlling for historical demographic composition, to examine whether the associations persist over these years.

RESULTS

The 576 included ZIP codes, nested within 21 cities, had a mean land area of 5.1 square miles (SD = 4.4), and a mean 2019 population of 34,113 (SD = 18,650) (Table 2). Information on the 21 included cities that had information on HOLC grading, historical demographic information, and NVDRS violent and firearm death counts are presented in Table 2. Over a third of the ZIP codes’ land area was not graded in the HOLC maps (mean = 48%; SD = 30%) indicating that these areas were not developed for residential occupancy in the 1930s and 1940s, 5% was graded A (SD = 11%), 12% was graded B (SD = 17%), 21% was graded C (SD = 22%), and 13% was graded D (SD = 21%) (Table 3). A total of 5,307 violent deaths were recorded in the NVDRS for 2019 in the included ZIP codes. Approximately 54% (n = 2,886) of those violent deaths recorded had a primary weapon type of “firearm” reported, allowing us to categorize them as a firearm death.

Results of the random intercept models examining violent deaths are presented in Table 4. In unadjusted Model 1a, there is a dose-response relationship between the proportion of land area graded within the ordinal HOLC grades and the incidence of violent death in 2019; however, the relationship between HOLC grade B compared to A was not significant at an alpha of 0.05. Compared to HOLC grade A, areas with HOLC grade C had 3 times greater incidence of violent death (IRR = 2.60; 95%CrI = 1.41, 4.84). Because the continuous HOLC variables are scaled from 0 to 1, the parameter estimates are interpretable as the association for ZIP codes where 100% of land area has the named zone compared to ZIP codes where 100% of land area is Grade A (i.e., the reference category). HOLC Grade D had 4 times increased incidence of violent death (IRR = 4.42; 95%CrI = 2.40, 8.20) compared to HOLC Grade A. In Model 1b, after controlling for the 1940 index of concentrated disadvantage and the ICE for 1940, associations were attenuated and were supported for only Grade D.

Results of the random intercept models examining firearm deaths are presented in Table 5. In unadjusted Model 1a, there is a dose-response relationship between the proportion of land area graded within the ordinal HOLC grades and the incidence of firearm death in 2019. Compared to HOLC Grade A, areas with HOLC Grade B had 4 times greater incidence of firearm death (IRR = 3.79; 95%CrI = 1.33, 11.04). HOLC Grade C had 6 times increased incidence of firearm death (IRR = 6.32; 95%CrI = 2.58, 15.81) and HOLC Grade D had 10 times increase incidence of firearm death (IRR = 9.66; CrI=3.97 to 24.03) compared to HOLC Grade A. In Model 1b, after controlling for the 1940 index of concentrated disadvantage and the ICE for 1940, associations were attenuated and supported for Grades B, C, and D. The results of the 2017 and 2018 data were similar and can be found in the appendix.

Figure 2 displays the results accounting for spatial non-stationarity (Model 2). Underlying this figure is a scatterplot of the observed values of the proportion of land area zoned C or D (x-axis) and the incidence of firearm death per 10,000 population on a log scale (y-axis). The referent city, Chicago, is shown as a black line. In that location, the ZIP codes had a minimum proportion of 6.2% of their land area Grade C or D, and a maximum proportion of 96.2%. The association was positive for most cities; however, the effects were significantly stronger in Baltimore. On the other hand, 4 of the 21 cities (Denver, Los Angeles, Portland, and San Francisco) had a slope that was significantly different from the slope of Chicago, demonstrating weaker associations than that of Chicago in our study universe.

DISCUSSION

Many studies in recent years have related historical redlining as a measure of structural racism to various health outcomes, including the incidence of violent and firearm death. This study advances this research by determining associations between redlining and violent and firearm deaths across the US while accounting for spatial non-stationarity. We found that associations between HOLC grades and violent death were strongest when comparing areas that were graded “D” to those graded “A.” We also found that associations between HOLC grades and firearm death are dose-responsive. Further, associations within local ZIP codes do not appear stable between cities, providing grounds for further research into non-stationarity.

Our findings are consistent with other studies examining redlining and firearm violence. Studies in Boston, MA,[33] Louisville, KY,[31] and Philadelphia, PA[32] all found increased rates of firearm violence in areas with lower HOLC grades. Across the extent of the US, our study finds a similar association between lower HOLC grades and both violent and firearm death. Poulson et al. found that changes to the built environment mediated the association between redlining and firearm violence.[33] Further, the authors found that poverty and public services also mediated the relationship between redlining and firearm violence. Understanding whether the relationship found in the literature holds across the extent of the US is important when the potential confounders on the pathways from redlining to firearm violence may differ between cities. Our findings emphasize the strong relationship between redlining and firearm violence regardless of the city-specific characteristics that may exist. Like the work of Jacoby et al.,[32] we found that the relationship between all forms of violent death and redlining was explained by the 1940 index of concentrated disadvantage, but this was not the case when examining the relationship between firearm death and redlining specifically. With such a long pathway between the creation of the HOLC maps and present-day violence, perhaps violence in previous time points predict rates of firearm violence specifically. Further research that examines the etiology of this dynamic, over time, was beyond the purview of this analysis but would add needed specificity to the nature the relationships observed in both studies.

While emerging research supports the positive association between redlining and firearm violence, the question remained whether this association varied by city.[67,68] Because the societal-level factors referenced in the social-ecological model may operate in different degrees in different geographic contexts,[69] examining non-stationarity in redlining remained important. Our study found that the association between redlining and modern-day firearm violence differed significantly between cities; that is, redlining overall did not affect firearm violence consistently across cities. This finding is important because it could both suggest HOLC policies were enacted differently in different cities and that redlining is only a single dimension of historical structural racism. There is emerging evidence from urban historians that the manner through which HOLC maps were shared and used varied widely. Literature examining the “disjuncture” between HOLC’s guiding theories, those depicted in the maps, and actual practice[41] may inform reasons why the effect of the HOLC map grading system and boundaries have varying degrees in cities across the US. Black Americans, for example, had different levels of access to HOLC loans based on the city they lived in. Additionally, different cities have different systems that reinforce the inequitable system of loan distribution.[70,71] A critical component of the definition of structural racism is that it requires mutually reinforcing inequitable systems.[16] Redlining is just one part of a historical legacy of disenfranchisement, racism, and disinvestment practices in specific areas of US cities. Selecting a singular illustration like the HOLC maps as a proxy for structural racism may overlook how discriminatory policies interplay and reinforce one another over time and space.

The results of this study point to the need for the examination of the interaction of different dimensions of structural racism, one of them being these HOLC maps, instead of examining these dimensions separately when considering their impact on racialized disparities related to firearm violence. Hardeman et al. outlines that this kind of complexity is imperative for anti-racist work in health and health research. To do so requires: understanding historical context (where redlining falls with the forces that shape urban development and population disinvestment), geographical context, the multifaceted nature of the ways that different forms of structural racism impact public health and potentiate health outcomes.[72] These factors are likely to vary city to city, require an understanding of city-contexts when creating, and implement interventions. Further, to address issues in temporal relationships, there is value to considering both historical and contemporary forms of structural racism in the housing market and in place of residence-based exposures on firearm violence victimization.[73] Examination of these dimensions of structural racism may inform city-specific policy and practices that most effectively reduce disparities in firearm violence.

This study should be interpreted with limitations in mind. The pathway between redlining as a proxy for structural racism in the 1930s to modern-day firearm violence is almost 9 decades long. While we do control for potential socioeconomic and demographic factors, we do not analyze other potentially non-spatially distributed confounders or examine potential mediators that may explain why certain areas of segregation have evolved and persisted over time. Further, archives indicated that HOLC maps may not have been as widely distributed as once hypothesized and lenders used other sources of information that may also have exacerbated racist and discriminatory thinking and polices.[19,20] However, the maps are a historic illustration of racialized hierarchicalization of urban space and are still a part of structural racism, although they clearly are only a singular dimension of structural racism. Another limitation is the issue of spatial misalignment. Demographic information and measures used to create the measure of concentrated disadvantage in this study are collected at the census tract level while our exposure and outcome measures are measured at the ZIP code level. Similar studies examining the relationship between redlining and various health outcomes have encountered similar spatial bias issues. Further, ZIP codes are a relatively arbitrary spatial unit that was designed by the United States Postal Service and there is a mismatch between the alignment of the ZCTA boundaries and the actual ZIP code boundaries themselves.[74–76] Spatial misalignment is an issue in most studies of the examination of redlining on health outcomes.

CONCLUSION

Examinations of place-based exposures, such as historical structural racism as captured through redlining practices, are vulnerable to threats common in spatial epidemiology, like non-stationarity. This multi-level and multi-city study examining the impact of redlining on violent and firearm death across the US found higher rates of both in areas with historically lower HOLC grades. Further, the association did not appear stable across cities. It is important to understand these findings in the context of structural racism which is the result of decades of discrimination brought forth by mutually reinforcing inequitable systems. Mediation analyses, like that of Poulson et al.,[33] examining impacts of racist economic marginalization, like redlining, should be conducted not only across the US but in specific cities to provide opportunities for reduction in firearm death especially. Analyses in violence prevention that incorporate time-varying confounding when exposure and outcome are separated by many decades may further inform policy recommendations.[77] By virtue of the large dataset including 21 large cities in the US, this study provides strong evidence that HOLC grades are indeed associated with present-day violence — especially firearm death. Examining the impact of structural racism as captured through the proxy of redlining demonstrates the historical legacy of disinvestment and discriminatory practices that perpetrate violence beyond the individual, shifting the focus from the marginalized communities experiencing the highest rates of firearm violence to the places and areas that perpetuated discriminatory practices. Opportunities for intervention must incorporate knowledge that the strength of the association of redlining and firearm death may vary between cities, and thus requires context-specific knowledge of the discriminatory practices on marginalized communities, lived experiences of communities, and their interaction with loan-based discrimination as depicted through HOLC maps.

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Highlights:

- Firearm violence is a major contributor to racial health disparities in the United States.
- Previous studies have operationalized structural racism through the historic redlining.
- Studies found associations between redlining and present-day firearm violence in select US cities.
- We find associations between HOLC grades and firearm death to be dose-responsive.
- The associations do not appear to be uniform across US cities.

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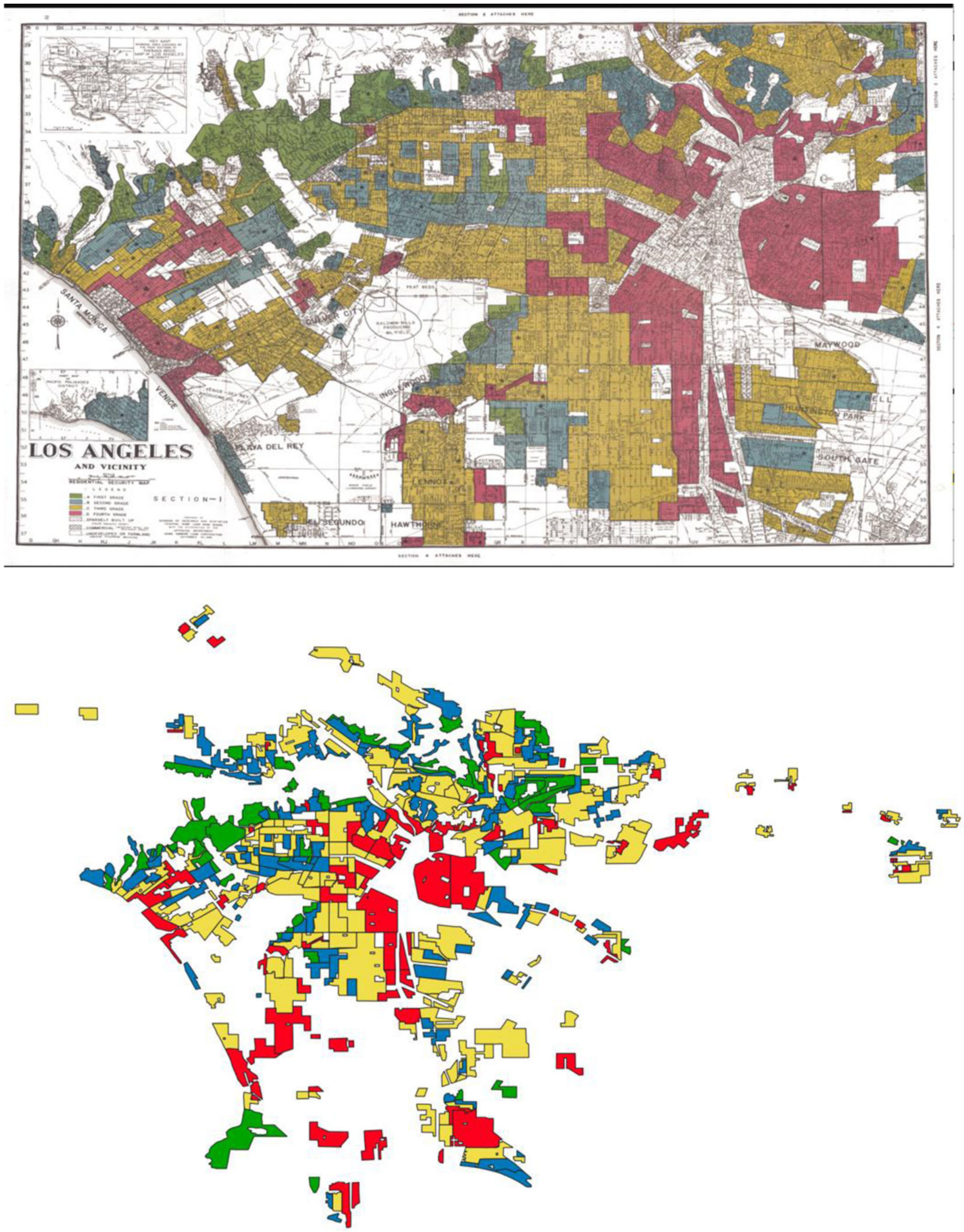

Figure 1.

The original and digitized versions of HOLC maps from Los Angeles from the *Mapping Inequality* project by the University of Richmond.

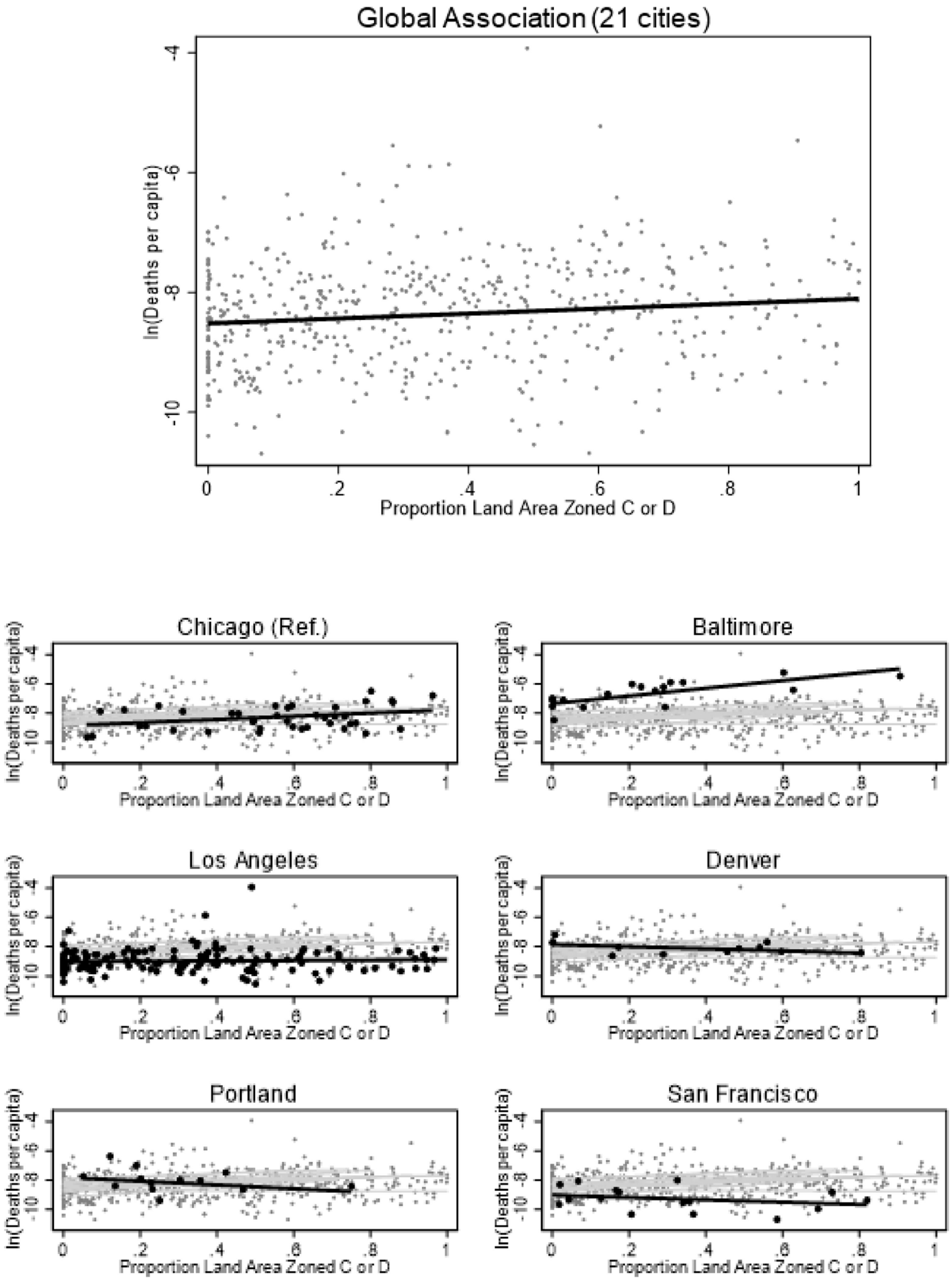

Figure 2.
Estimated association between the proportion of land area zoned C or D and firearm deaths per population in 2019; ZIP codes (n=576) nested within cities (k=21). Associations are shown for the referent city (Chicago), cities with positive interactions compared to the referent city (Baltimore) and cities with negative interactions compared to the referent city (Los Angeles, Denver, Portland, San Francisco).

Table 1.

Pearson correlation coefficients; 1940 Census tract centroids US (n=722)

	1	2	3	4	5	6
1. Age ≥ 25 years without a High School certificate	1.00					
2. Tenant occupied dwellings (%)	.22*	1.00				
3. Dwellings without a radio (%)	.34*	.41*	1.00			
4. Dwellings without a mechanical refrigerator (%)	.71*	.39*	.60*	1.00		
5. Dwellings without central heating (%)	.25*	.14*	.36*	.52*	1.00	
6. Dwellings with ≥ 1 person per room (%)	.68*	.33*	.54*	.67*	.45*	1.00

* $p < 0.05$

Table 2.

Descriptive statistics of 21 cities with available HOLC data, 2019 violent death data, and 1940's Census Data

City	Number of zip codes	Mean Population Size per Zip Code	Mean percentage Zip Code area with HOLC designation				
			No HOLC designation	HOLC "A" designation	HOLC "B" designation	HOLC "C" designation	HOLC "D" designation
Akron, OH	11	13772	0.37	0.10	0.15	0.26	0.12
Atlanta, GA	18	27040	0.69	0.04	0.07	0.11	0.09
Baltimore, MD	18	33112	0.51	0.05	0.19	0.14	0.11
Boston, MA	17	23070	0.42	0.01	0.04	0.23	0.30
Chicago, IL	40	54698	0.36	0.00	0.09	0.35	0.20
Cleveland, OH	33	24536	0.53	0.06	0.11	0.18	0.12
Columbus, OH	10	26994	0.53	0.02	0.15	0.23	0.08
Denver, CO	12	31668	0.50	0.05	0.11	0.25	0.09
Detroit, MI	53	24109	0.35	0.04	0.10	0.31	0.21
Indianapolis, IN	19	27543	0.48	0.04	0.05	0.28	0.14
Los Angeles, CA	147	35118	0.52	0.05	0.10	0.24	0.09
Louisville, KY	15	20900	0.43	0.08	0.11	0.23	0.16
Minneapolis, MN	14	23463	0.46	0.10	0.27	0.10	0.07
Oklahoma City, OK	13	14357	0.62	0.11	0.05	0.14	0.08
Philadelphia, PA	42	34619	0.42	0.05	0.18	0.10	0.24
Pittsburgh, PA	37	18482	0.55	0.04	0.13	0.17	0.11
Portland, OR	14	23030	0.51	0.05	0.14	0.22	0.08
San Francisco, CA	17	34945	0.49	0.05	0.16	0.20	0.10
Seattle, WA	10	31286	0.48	0.03	0.20	0.16	0.13
St.Louis, MO	24	22275	0.42	0.11	0.24	0.15	0.08
St.Paul, MN	12	31136	0.51	0.07	0.11	0.15	0.16

Table 3.

Descriptive Statistics of 722 US ZIP codes with available HOLC data, violent death data, and 1940's Census Data

	Mean (SD)
Violent Deaths	**9.21 (13.13)**
Firearm Deaths	**5.01 (6.94)**
HOLC Designation	
A	**0.05 (0.11)**
B	**0.12 (0.17)**
C	**0.21 (0.22)**
D	**0.13 (0.21)**
None	**0.48 (0.30)**
Average Population Size	**30106 (18274)**
Index Variables	
Proportion of population aged >25 without a high school certificate	**0.63 (0.19)**
Proportion of homes that were renter occupied	**0.51 (0.22)**
Proportion of homes without a radio	**0.04 (0.07)**
Proportion of homes without a mechanical refrigerator	**0.33 (0.22)**
Proportion of homes without central heating	**0.38 (0.33)**
Proportion of homes with more than one person per room	**0.12 (0.09)**
ICE1940	**0.91 (0.23)**

Table 4.

Bayesian conditional autoregressive Poisson models for 2019 violent death incidence; 1940s ZIP codes, USA (n=576)

	Model 1a	Model 1b
	OR (95% CI)	**OR (95% CI)**
No HOLC designation	1.93 (1.07 to 3.51)	1.37 (0.72 to 2.60)
HOLC “B” designation	1.76 (0.86 to 3.65)	1.46 (0.70 to 3.06)
HOLC “C” designation	2.60 (1.41 to 4.84)	1.87 (0.97 to 3.62)
HOLC “D” designation	4.42 (2.40 to 8.20)	2.54 (1.24 to 5.25)
Index of concentrated disadvantage		1.16 (1.04 to 1.29)
ICE 1940		1.03 (0.79 to 1.33)
Spatially lagged no HOLC designation		
Spatially lagged HOLC “B” designation		
Spatially lagged HOLC “C” designation		
Spatially lagged HOLC “D” designation		

Table 5.

Bayesian conditional autoregressive Poisson models for 2019 firearm death incidence; 1940s ZIP codes, USA (n=576)

	Model 1a	Model 1b
	OR (95% CI)	**OR (95% CI)**
No HOLC designation	3.21 (1.36 to 7.82)	2.49 (0.98 to 6.47)
HOLC "B" designation	3.79 (1.33 to 11.04)	3.32 (1.14 to 9.85)
HOLC "C" designation	6.32 (2.58 to 15.81)	4.97 (1.91 to 13.12)
HOLC "D" designation	9.66 (3.97 to 24.03)	6.28 (2.22 to 18.09)
Index of concentrated disadvantage		1.12 (0.96 to 1.30)
ICE 1940		0.96 (0.67 to 1.36)
Spatially lagged no HOLC designation		
Spatially lagged HOLC "B" designation		
Spatially lagged HOLC "C" designation		
Spatially lagged HOLC "D" designation		

Table 6.

Bayesian conditional autoregressive Poisson models for 2017 firearm death incidence; 1940s ZIP codes, USA (n=691)

	Model 1a	Model 1b
	OR (95% CI)	**OR (95% CI)**
No HOLC designation	3.55 (1.46 to 8.87)	3.30 (1.29 to 8.71)
HOLC “B” designation	3.92 (1.36 to 11.57)	3.80 (1.30 to 11.40)
HOLC “C” designation	7.62 (3.09 to 19.23)	7.15 (2.77 to 18.94)
HOLC “D” designation	13.42 (5.41 to 34.18)	11.81 (4.19 to 34.13)
Index of concentrated disadvantage		1.04 (0.90 to 1.19)
ICE 1940		0.98 (0.72 to 1.33)
Spatially lagged no HOLC designation		
Spatially lagged HOLC “B” designation		
Spatially lagged HOLC “C” designation		
Spatially lagged HOLC “D” designation		

Table 7.

Bayesian conditional autoregressive Poisson models for 2018 firearm death incidence; 1940s ZIP codes, USA (n=732)

	Model 1a	Model 1b
	OR (95% CI)	OR (95% CI)
No HOLC designation	3.83 (1.63 to 9.26)	2.89 (1.17 to 7.29)
HOLC “B” designation	5.68 (2.05 to 16.14)	4.89 (1.75 to 13.97)
HOLC “C” designation	7.17 (2.99 to 17.63)	5.52 (2.22 to 14.06)
HOLC “D” designation	13.19 (5.45 to 32.70)	8.10 (2.96 to 22.62)
Index of concentrated disadvantage		1.14 (0.99 to 1.32)
ICE 1940		0.97 (0.70 to 1.34)
Spatially lagged no HOLC designation		
Spatially lagged HOLC “B” designation		
Spatially lagged HOLC “C” designation		
Spatially lagged HOLC “D” designation		