Neighborhood historical redlining, present-day social vulnerability and sports and recreational injury hospitalizations in the United States

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SCIENTIFIC ABSTRACT

Historical redlining, a discriminatory practice of the 1930s, present-day social vulnerability (**SVI**), and sports and recreational injury (**SRI**) hospitalizations are interconnected topics that highlight the intersection of race, class, and health in the United States but the relationships have not been studied to date. Thus, the overall aim of this dissertation is to examine the effects of historical redlining and present-day social vulnerability on SRI hospitalizations in the United States. The first study systematically reviewed studies that examined the relationships between neighborhood characteristics and SRI using multilevel modeling approach. Studies reviewed show that certain neighborhood factors, such as living in urban communities, were associated with increased risk of SRI. The second study examined the association between historical redlining and present-day neighborhood SVI in the United States. Results show that formerly redlined areas have higher SVI presently. The third study examined the association between historical redlining and present-day SRI hospitalization in the United States. Results show that redlining was not associated with increased odds of SRI hospitalizations, but was associated with longer length of hospital stay (**LOS**) among Black and Hispanic patients, and higher total hospital charges among Hispanic patients. The fourth study examined the association between individual and neighborhood social vulnerability and sports and recreation-related traumatic brain injury (**SR-TBI**) hospitalizations among pediatric patients in the United States. Results show that Native American children had higher odds of hospitalization for SR-TBI, longer LOS, but lower odds of discharge to post-acute care compared to White children. Older age was associated with higher odds of hospitalization and longer LOS while male sex was associated with shorter LOS for SR-TBI in children. Compared to children with private insurance, children with public insurance had longer LOS while uninsured children had shorter LOS. Also, hospitalization in neighborhood with higher overall SVI was associated with longer LOS. This study advances our knowledge on the impact of structural racism on present-day SRI outcomes and will inform policy makers to prioritize health equity by addressing the underlying social determinants of health and the root causes of disparities in SRI outcomes.

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GENERAL ABSTRACT

Every year, around 9 million people get hurt while playing sports or participating in recreational activities in the United States. Out of these, more than a third go to the emergency department for treatment, and several thousands need to stay in the hospital because their injuries are more serious. Even though only a small number of sports and recreational injuries (**SRI**) require hospitalization compared to those treated in the emergency department or outpatient clinics, these injuries tend to be more severe. They can cause significant harm to a person's physical, mental, and emotional well-being, and they also put a lot of pressure on the healthcare system and society as a whole. This dissertation assessed how historical discrimination against certain neighborhoods, called redlining, and present-day social vulnerability affect sports and recreational injury hospitalizations in the United States. This research found that the neighborhood where people live or are hospitalized matter for how often they are hospitalized for SRI, their length of stay in hospital, the amount of money they pay while in hospital, and how often they receive follow-up care after leaving hospital. While historical redlining was not directly linked to higher odds of hospitalization, it was associated with longer hospital stays for Black and Hispanic patients and higher costs for Hispanic patients. This research also found that children from socially vulnerable backgrounds were more likely to be hospitalized for sports-related traumatic brain injuries (**SR-TBI**) and stay in hospital longer, but were less like to receive follow-up care after leaving hospital. For instance, children from Native American backgrounds were three times more likely to be hospitalized for SR-TBI and stayed in the hospital 27% longer, but were 99.9% less likely to receive follow-up care after leaving hospital compared to White children. Also, children with public health insurance tended to have longer stays in hospital for SR-TBI compared to those with private health insurance. This research highlights how structural discrimination can impact health outcomes, and suggests that policymakers should address the root causes of health disparities in order to promote health equity.

Dedication

To everyone who believed in me, supported me, inspired me, prayed for me and gave me a second chance.

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Attribution

My PhD advisor, Dr. Charlotte Baker, an Assistant Professor of Epidemiology in the Department of Population Health Science at Virginia Tech aided in the writing and research of one of the published chapters (Chapter 2) of this dissertation titled: “Neighborhood risk factors for sports and recreational injuries: a systematic review of studies applying multilevel modeling techniques.” Dr. Baker served as a co-author on the published manuscript and assisted in conceptualizing the systematic review, screening articles for eligibility, carrying out study quality assessment of included articles, verifying the validity of the extracted data, revising the manuscript. and approving the final version for publication.

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Chapter 1: Introduction

1.1 Research Context and Justification

Neighborhood historical redlining, present-day social vulnerability, and sports and recreational injury (**SRI**) hospitalizations are interconnected topics that highlight the intersection of race, class, and health in the United States.[1] Historical redlining refers to the practice of denying loans and other services to individuals and communities based on their race or ethnicity, which led to the systematic disinvestment in predominantly non-white neighborhoods.[2] This practice has had long-lasting effects on the health and well-being of these communities, as they continue to experience higher rates of poverty, crime, and inadequate access to healthcare services.[1,3–21]

Today, these historically redlined neighborhoods also face high levels of social vulnerability.[1] Social vulnerability refers to the potential negative impact of external stresses and hazards on a population's health and well-being.[22] Factors such as poverty, disability, lack of access to healthcare, inadequate housing and lack of access of transportation increase the likelihood of adverse health outcomes in these communities.[23–25] Social vulnerability is compounded by systemic racism, which limits opportunities for economic mobility and political power, further exacerbating the effects of redlining.[1,24]

Sports and recreational activities are often seen as a way to promote physical activity, improve health, and foster social connections.[26,27,28] However, research has shown that participation in sports and recreational activities can lead to an increased risk of injury,[29–31] particularly in vulnerable populations who are more likely to play in poorly maintained or unsafe facilities. In addition, low-income families may not have access to proper equipment, medical care, or insurance to cover the costs of injuries.[32]

Hospitalizations due to sports and recreational injuries can also exacerbate existing health disparities. Those living in historically redlined and socially vulnerable neighborhoods may have limited access to healthcare services or may not be able to afford the cost of hospitalization.[17] This can lead to delayed treatment, chronic pain, and long-term disability.

The intersection of historical redlining, present-day social vulnerability and SRI hospitalizations highlights the need for a more comprehensive approach to addressing health disparities in the United States. It is important to understand and address the root causes of present-day social vulnerability, such as systemic racism and poverty, while also ensuring that all individuals have access to safe and affordable sports and recreational opportunities and healthcare services. Understanding this intersection and addressing social vulnerability will help us promote health equity and improve the overall well-being of individuals and communities in the United States.

1.2 Research Aims and Significance

This dissertation research examined the effects of neighborhood historical redlining and present-day social vulnerability on SRI hospitalizations in the United States. The broad aims of this study were to:

1) Systematically review studies that examined the relationships between neighborhood characteristics and SRI using multilevel modeling approach,
2) Examine the association between historical redlining and present-day social vulnerability in the United States,

3) Examine the racial and ethnic disparities in the association between historical redlining and present-day SRI hospitalization in the United States, and
4) Examine the association between individual and neighborhood social vulnerability and sports and recreation-related traumatic brain injury (**SR-TBI**) hospitalizations among pediatric patients in the United States.

In this research, I used multilevel generalized linear mixed models (**GLMM**) to address my study aims. I identified how historical redlining, an indicator of structural racism, influence present-day neighborhood social vulnerability in the United States. I also identified the racial and ethnic disparities that exist in the associations between historical redlining and present-day risk of SRI hospitalization, length of stay (**LOS**), and total hospital charges, and how present-day neighborhood social vulnerability moderate these associations. In addition, I identified how social vulnerability influence SR-TBI hospitalizations among pediatric patients and showed the importance of understanding the individual as well as neighborhood characteristics that increase vulnerability to SR-TBI. Outcomes from this study include advancing the practical knowledge of the impact of structural racism on present-day health outcomes and neighborhood conditions, and improving the understanding of the intersection of structural racism, social vulnerability and SRI hospitalizations. These outcomes will help in increasing health equity and environmental justice.

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Chapter 2: Neighborhood Risk Factors for Sports and Recreational Injuries: A Systematic Review of Studies Applying Multilevel Modeling Techniques

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Abstract

Background: Sports and recreational activities are the most commonly reported cause of injury-related emergency department (ED) visits among children and young adults in developed countries, yet studies about the effect of neighborhood environment on sports and recreational injuries (SRI) are very limited. The aim of this study was to systematically review studies that apply multilevel modeling approach in examining the relationships between SRI and neighborhood-level risk factors.

Data sources: A systematic search of peer reviewed English language articles was conducted in four electronic databases including PubMed (1992-2020), CINAHL (2000-2020), Sports Medicine and Education Index (1996-2020), and Web of Science (1991-2020).

Study selection: Selected studies were observational or experimental studies of people of all ages across the world that assessed neighborhood risk factors for SRI (or all injuries including SRI) using multilevel regression analysis.

Data synthesis: Nine studies - five cross-sectional, two prospective cohort, and two incidence studies – were selected out of a potential 1510. Six studies used secondary data and three used primary data. Only three studies examined SRI as the main or one of the main outcomes. These studies showed that neighborhood-level factors such as higher socioeconomic context, lower street connectivity, and living or attending schools in urban communities, were associated with increased risk of SRI. Most studies did not provide a justification for the use of multilevel regression and the multilevel analytical procedure employed and quantities reported varied. The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Institutes of Health) was used to assess the quality or risk of bias of each study. Four quality assessment criteria out of 15 were met by all nine studies. The quality assessment ratings of the reviewed studies were not correlated with the quality of information reported for the multilevel models.

Conclusion: Findings from this review provide evidence that neighborhood-level factors, in addition to individual-level factors, should be taken into consideration when developing public health policies for injury prevention. Considering the limited numbers of studies that were identified by this systematic review, more multilevel studies are needed to strengthen this evidence in order to better inform SRI prevention policy decisions.

Keywords: Sports, Recreation, Injury, Neighborhood, Systematic review, Multilevel models.

2.1 Background

Exercise is now recognized as an important factor associated with improved health outcomes in people [1,2]. It is reported to lower the risk of obesity, diabetes, cardiovascular disease, depression, anxiety and some cancer [3], and as a result, has been extensively promoted as part of a healthy lifestyle [2]. Recent report shows increasing participation in physical activity in the United States with about 230 million Americans aged 6 years and over (76 %) taking part in physical activities in 2020, up from 214 million in 2015 (73%) [4]. While increased participation in physical activity provides many health benefits, increased exposure to physical activity also increases injury risk, posing a growing public health concern [5,6].

Sports and recreational activities are the most commonly reported cause of injury-related emergency department (**ED**) visits among children and young adults in developed countries [5,6]. In the United States for instance, the average annual number of sports and recreational injuries (**SRI**) episodes is estimated to be about 8.6 million with more than 3 million resulting in visits to hospital ED [6]. This makes injury, including SRI, one of the main cause of morbidity, disability, and surplus health expenditures in children and young adults in developed countries [7].

Although SRI poses a growing and important public health concern, studies about these injuries are limited compared to other types of injuries. One of the reasons for the poor attention to SRI problem is because they are often less severe than other types of injuries such as those from motor vehicle accidents and as a result, most injury surveillance systems for fatal and hospitalized injuries have excluded much of the burden of SRI with the exception of traumatic brain injury (**TBI**) [2,8]. SRI are often included in state and national databases such as those from the Agency for Healthcare Research and Quality's Health Care Utilization Project [9] albeit without many injury-specific details such as playing surface. Additional SRI-specific surveillance exists for professional sports [10], collegiate sports [11], and active people of various ages [12–14], yet are not inclusive of all physical activity-related injuries across the lifespan especially because many SRI do not require medical attention. To address this growing public health challenge, it is important to adequately document injuries resulting from sports and recreational activities and understand the socio-ecological factors (including individual and contextual) that influence SRI.

To date, only a few studies have examined how both individual (e.g., age, sex, or race/ethnicity) and contextual factors (e.g., neighborhood socioeconomic or built environments) are associated with SRI [15–17]. The majority of studies focus on the individual-level factors while paying less attention to important contextual factors such as the neighborhood-built and socioeconomic environment. Research for bicycle or walking injuries related to motor vehicle crashes often involves analyzing geospatial data for contextual factors (such as street connectivity, access to sidewalks, bicycle lanes, parks, and recreational facilities, etc.) yet this type of analysis is not frequently applied to the study of SRI. This limitation may be more closely related to the availability of contextual factors within SRI data sources, requiring more complex methods such as data linkage and analysis of nested or hierarchical data. This complexity is evident in the simple, and sometimes inappropriate, methods employed in studies assessing the influence of contextual factors on SRI risk. In studies where these associations are considered, the interactive effects between individual and contextual factors (cross-level interactions, **CLI**) are often not explored. The presence of CLI could cause variation in SRI risk among people with, for example, similar socioeconomic status but who live in neighborhoods with different access to parks and recreational facilities. Understanding CLI is important because it will help in understanding how individuals in characteristically different neighborhoods respond to interventions targeted at preventing or reducing the risk of SRI.

Classical regression approaches for analyzing the association between SRI and various individual and contextual factors are limited in their ability to simultaneously assess relationships occurring at multiple levels [18]. This deficiency of the classical regression approach can be resolved by utilizing a multilevel modeling (**MLM**) approach for analyzing data that are nested or hierarchical in nature [18]. Multilevel regression is an advanced form of classical regression that is appropriate for quantifying associations of hierarchically structured data (e.g., individual nested within neighborhood), as it can characterize associations within and between groups, and account for variation in outcome variables attributed to individual-level and neighborhood-level exposures [19].

Despite the advantages MLM have over the classical regression approach, no systematic review has documented the application of this approach for analyzing the association between neighborhood risk factors and SRI. This review was carried out in order to encourage use of the multilevel approach in analyzing contextual data and to promote multilevel interventions in reducing SRI risks. A previous review examined how unintentional injury in childhood are related to neighborhood risk factors [20], while another review examined how fatal and non-fatal injuries are related to neighborhood socioeconomic factors [21]. In our review, we were interested in all neighborhood determinants of SRI alone in all age groups.

The main objective of this review is to systematically review studies that apply a multilevel modeling approach in assessing the relationships between SRI and neighborhood-level risk factors. The specific objectives are to: 1) examine how neighborhood-level risk factors is related with SRI when considered simultaneously with individual-level factors that influence

SRI; 2) identify and characterize the multilevel methods or approach from articles selected for review; and 3) make recommendations on how to overcome identified gaps in research and statistical methodology. This study offers a valuable synthesis for policymakers, public health experts and other stakeholders concerned about reducing the burden of SRI.

2.2 Methods

2.2.1 Registration

This systematic review was designed following the guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (**PRISMA**) and the protocol was registered with the International Prospective Register of Systematic Reviews (**PROSPERO**) on January 18, 2021 (Registration Number: CRD42021227119).

2.2.2 Eligibility criteria

Studies were selected for our systematic review based on the following criteria: 1) study types: we included observational studies such as case-control studies, cohort studies, incidence studies, prevalence studies, cross-sectional studies, and longitudinal studies. We also included experimental studies such as randomized controlled trials. Studies were restricted to journal articles reported in English language with review articles and meta-analysis excluded from our study. 2) participants: we included studies that examined human population of all age groups in countries across the world. 3) exposures: we included studies that examined neighborhood-level exposure variables that are risk factors for SRI, such as built or physical environment, neighborhood socioeconomic environment, neighborhood social vulnerability, neighborhood social inequality, and neighborhood social capital etc., in addition to individual-level risk factors. Our definition of socioeconomic environment did not include social capital. Socioeconomic environment was defined as the intersection of social and economic factors that determine the distribution of resources, money and power in a community [22,23]. This is often determined by social standing factors such as marital status, occupation, religion, family, income, class, or age [23] and is related to the strength of your social cohesion (i.e. social relationships) [24]. The stronger your social cohesion, the more likely you are to be able to rely on others to help you when you need it and the greater your social capital. Social capital was defined as the network you belong to and the types of values you hold [24]. Your social capital may influence your socioeconomic environment but this is tempered by socioeconomic determinants. 4) outcomes: we included studies in which the outcome (or one of the outcomes) was SRI; outcome included a broader injury category while exposure variables in the multilevel model included sports and recreation activities, playgrounds and recreational facilities, or other sports and recreation-related exposure variables; or outcome included a broader injury category while sports and recreational activities and/or playgrounds and recreational facilities were reported as one of or the main risk factors for injury. SRI was defined as damage to the body caused by exposure to an external force related to sport, recreation, or physical activity. 5) data analysis: we included studies that used multilevel regression analysis to examine the association between individual-level and neighborhood-level exposures and SRI (or all injuries including SRI).

2.2.3 Information Sources

The search for studies that meet our eligibility criteria was conducted in four electronic databases which include: 1) PubMed (1992-Present), 2) CINAHL from EBSCOhost (2000-Present), 3) Sports Medicine and Education Index (Proquest) (1996-Present), and 4) Web of Science from Clarivate Analytics (1991-Present). Reference lists of previously published systematic reviews were also scanned for additional studies. The final search of electronic databases was run on

December 3, 2020. The same search term was used in all the electronic databases; however, the search filters varied depending on the options available in each database.

2.2.4 Search Strategy

We conducted literature searches for systematic reviews related to our topic in several electronic databases and PROSPERO to ensure that no previous or ongoing studies has been or was being carried out on our planned topic of study. We then developed our search strategy in consultation with a librarian with expertise in systematic reviews in Population Health Sciences. Based on the eligibility criteria listed above, we developed search terms that covered a wide range of articles related to our topic using special symbols, including truncation and quotation marks, and Boolean operators, to combine search words or phrases. Literature search words or phrases were developed using a combination of test words or phrases related to sports and recreational activities, injuries, contextual exposure variables, and multilevel modeling. We used the same search terms in all the electronic databases and limited our literature search to human subjects, English language, and peer review academic journals. The search strategy used in the electronic databases is listed below:

(environment* OR context* OR "built environment" OR "physical environment" OR neighborhood OR neighbourhood OR "neighborhood environment" OR "neighbourhood environment" OR "neighborhood built environment" OR "neighbourhood built environment" OR "neighborhood physical environment" OR "neighbourhood physical environment" OR communit* OR municipal OR urban* OR city OR cities OR town OR towns OR walkability OR connectivity OR built OR building* OR street OR streets OR "green space" OR greenspace OR park OR "recreation* facilit*" OR "environmental design" OR "socioeconomic" OR "socioeconomic status" OR "neighborhood socioeconomic status" OR "socioeconomic environment” OR “social environment” OR “social inequit*” OR “social inequalit*” OR “social determinant*” OR “political system*” OR “health disparit*” OR “social identification” OR “racial composition” OR “social vulnerability index” OR “residence characteristics” OR “residential segregation” OR “income inequit*” OR “income inequalit*”) AND (“motor activit*” OR sport OR sports OR athlete* OR recreation* OR “leisure activit*” OR “physical fitness” OR “physical exertion” OR “physical endurance” OR “physical activit*” OR exercis* OR “active living” OR “active lifestyle*” OR play OR “outdoor activit*” OR walk* OR run OR running OR bike OR biking OR bicycle OR bicycling OR cycle OR cycling OR “active transport*” OR “active transit” OR “active commuting” OR “physically active” OR fitness OR baseball OR basketball OR boxing OR “cricket sport” OR football OR golf OR gymnastics OR hockey OR “martial arts” OR mountaineering OR “racquet sports” OR tennis OR jog OR jogging OR skating OR “snow sport*” OR skiing OR soccer OR “track and field” OR volleyball OR walking OR “water sports” OR swimming OR “weight lifting” OR wrestling OR camping OR dancing OR hobbies OR gardening) AND (injury OR injuries OR wound OR wounds OR trauma* OR rupture OR fracture OR sprain* OR strain* OR avulsion OR concussion) AND ("multilevel model*" OR "multi-level model*" OR "multilevel regression" OR "multi-level regression" OR "multilevel analysis" OR "multi-level analysis" OR “multilevel logistic regression” OR “multi-level logistic regression” OR “hierarchical model*” OR “hierarchical regression” OR “hierarchical linear model” OR “hierarchical logistic regression” OR “random effects model*” OR “random coefficient model*” OR “mixed model*” OR “mixed effect model*”) NOT ("systematic review" OR “systematic analysis” OR "literature review" OR review OR “meta-analysis”)

2.2.5 Data management

Literature search results from the four electronic databases were uploaded into a citation manager, EndNote. Literature search results were then exported from EndNote into COVIDENCE, a web-based software that facilitates collaboration between reviewers during the process of screening and selection of articles. Duplicate articles were automatically removed by COVIDENCE and proper verification of articles' details were followed to ensure that they were actual duplicates.

2.2.6 Selection process

Screening of titles and abstracts of articles generated from electronic databases search results were carried out by the two authors using COVIDENCE software. The screening was based on the eligibility criteria for articles listed previously. Articles that appeared to meet our inclusion criteria were selected and went through full text screening by both reviewers. Disagreements between the two authors were resolved by discussion.

2.2.7 Data collection process

Articles selected after full text screening went through the data extraction stage which was carried out by the first author and verified by the second author. Data extraction sheet was developed following the Matrix Method [25] and the following information was collected: name of first author, year of publication, title of article, name of publication journal, country of study, study design, participant information (e.g., sample size, age, sex), data type and date of collection, geographical extent of area level, area-level measures, individual-level measures, measures of outcomes (i.e., SRI or total injuries including SRI), statistical method used, and main findings.

2.2.8 Study quality assessment

The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies of the National Institute of Health (NIH) was used to assess the quality or risk of bias of each study selected in our systematic review [26]. The NIH tool is based on 14 assessment criteria with a score of yes, no, cannot determine (CD), not applicable (NA), and not reported (NR) for each of the criteria. In addition to the NIH 14 criteria, an assessment criterion that determined if enough information was provided to know if the appropriate multilevel approach had been used was included. Therefore, a total number of 15 points were awarded to studies based on the number of "yes" answers and each study's quality and risk of bias were assessed on items related to research question, study population, sample size justification, exposure and outcome measurements, participation and follow-up rates, and statistical analyses. The quality assessment of studies was independently conducted by the two authors. Discrepancies were resolved by discussion.

2.3 Results

Of the 1510 records identified from searching four electronic databases and reference lists of other studies, only nine (9) were included in our systematic review analysis (**Figure 2.1**).

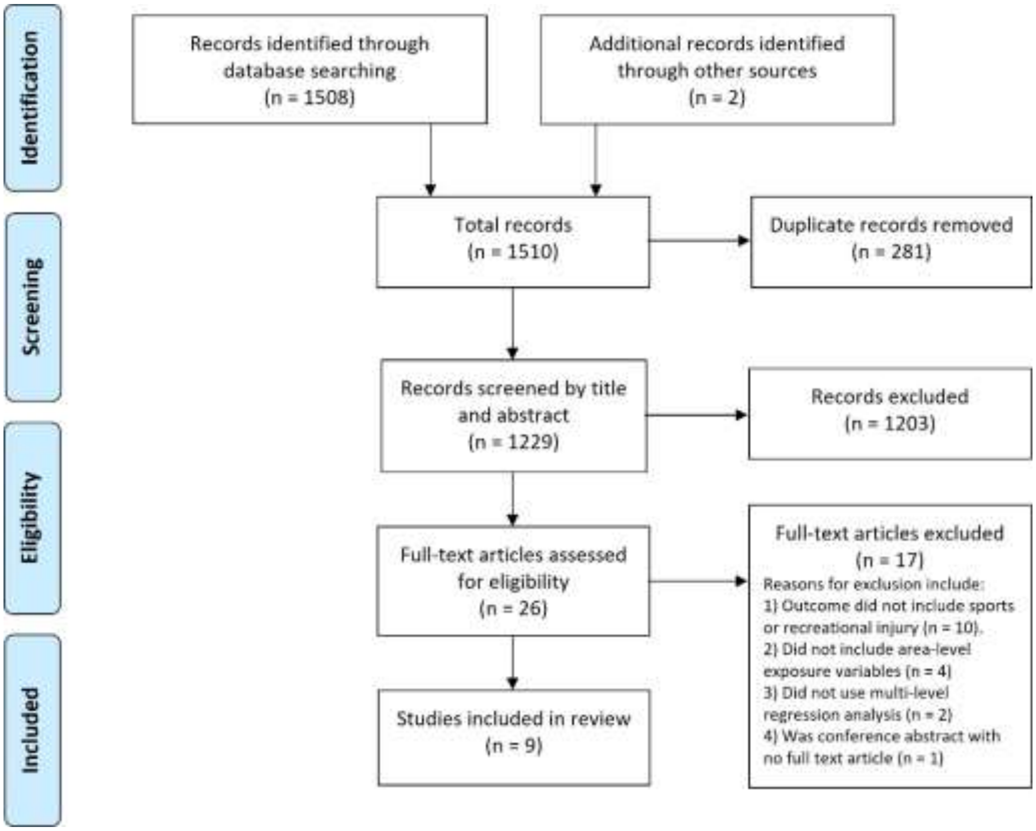

Figure 2.1: PRISMA flowchart of study selection.

2.3.1 Study characteristics

The characteristics of the studies included in this systematic review are summarized in **Table 2.1**. Among the final nine studies selected for the systematic review, five were cross-sectional studies [15–17,27,28], two were prospective cohort studies [29,30], and another two were incidence studies [7,31 32]. Six of the nine studies used secondary data collected by other organizations or from records of emergency department visits [7,15–17,28,31] while the remaining three used primary data collected by the researchers directly [27,29,30]. Almost half of the studies (four) were carried out in North America (all four of them in Canada and, surprisingly, none in the United States) [15–17,28], followed by Europe (three in total; two in the United Kingdom [7,29] and one in Sweden [31]), South America (one in Brazil [27]), and Africa (one in Uganda [30]).

The size of the study population at the individual level ranged from 1,000 participants to 1,056,064 person-years (Median = 9,021) with four of the studies having a population greater than 20,000. All nine articles included in our review studied children and adolescent (≤ 16 years old) even though all age groups were considered in this study. For studies in which the sex of participants was reported, approximately half of the populations were male.

In seven studies, individual and family were combined into a single exposure level (individual/family), resulting in two exposure levels for analysis – individual/family and neighborhood. In another study, individual and family were considered as distinct exposure levels, resulting in a total of three exposure levels – individual, family, and neighborhood [29]. In the final study, neighborhood was divided based on size resulting in three exposure levels under consideration – individual, enumeration district (i.e., smallest area with available census data), and social area (i.e., a group of enumeration districts) [7]. About half of all studies (4) defined the geographical extent of neighborhood by administrative area (e.g., municipality) and census area (i.e., geographical area defined for counting and recording information about a population) [7,27,29,31], while another 4 defined neighborhood by buffers (i.e., a specified distance surrounding a geographic feature such as school) [15–17,28]. For studies that used buffers to define neighborhood, a 1km or 5km radius was used as buffer size.

Neighborhood-level exposure variables used in all studies can be grouped into five main categories (**Table 2.2**) and they included: socioeconomic environment, physical environment, neighborhood crime levels and safety measures, social capital and social cohesion, and urban-rural geographic location; with socioeconomic environment being the most commonly studied neighborhood-level variable (n = 7 studies). Examples of socioeconomic neighborhood environment variables considered include: material deprivation, home ownership status, immigration status, lone parent status, poverty, housing value, employment status, education, and income while the examples of physical environment variables considered include: playgrounds, parks and recreational facilities, population density, street or road connectivity, permanent road access, pedestrian controlled lights, zebra crossings, total road lengths etc.

Only three of the studies considered SRI as an outcome or one of the outcome variables (**Table 2.2**) [15–17]. The other studies focused on a broader category of injury as outcome variable but included sports and recreation-related exposure variables in the multilevel model or reported sports and recreation-related activities or facilities as a main cause of injury.

2.3.2 Study quality assessment

The report for the quality assessment of studies included in this systematic review is contained in **Table 2.3**. Four quality assessment criteria were met by all studies and they include: 1) clearly specified and defined study population, 2) study subjects' selection from similar population at same time period, and pre-specification and uniform application of inclusion and exclusion criteria for all study participants, 3) statistical adjustment for key confounding variables, and 4) provision of adequate information to know that the appropriate multilevel technique was used and applied correctly. Where applicable, all studies measured different level for exposures that can vary in amount or level, and all studies, except one, provided clearly stated research objectives. Justification of sample size, description of statistical power, or estimation of variance and effect size was provided in six of the studies. Only a few studies provided report of study participation rate of $\geq 50\%$ for eligible persons ($n = 4$), measured exposures of interest prior to measuring study outcomes ($n = 2$), and had sufficient timeline to increase the probability of finding significant association between exposure and outcome if it existed ($n = 2$). The median assessment score for included studies is 7 out of 15 (range: 5 to 11).

Table 2.1: Characteristics of studies included in the review.

Study ID	Authors and year of publication	Title and journal	Purpose of study	City/ Region/ Country	Study design	Study population/ number of data level	Age (year)	Male (%)	Type of injury data and date of collection	Geographical extent of neighborhood level
1	Haynes, Reading & Gale. 2003.	Household and neighborhood risks for injury to 5-14 year old children. *Soc Sci Med*.	Are household and neighborhood risk factors independently associated with injury in children?	Norwich, United Kingdom	Incidence study	22771 children in total. Three levels: individual/family, enumeration districts (N=347) and social areas (N=21).	5-14	51.2 days at risk	Secondary data; 1999/2000 accident records of the Accident and Emergency Department at Norfolk/Norwich Hospital.	Enumeration districts (which are composed of about 150-200 households and are the smallest area with available census data), and social areas (i.e., groups of neighboring enumeration districts with similar Townsend material deprivation index).
2	Sellström, Guldbrandsson, Bremberg, Hjern & Arnoldsson. 2003.	Association between childhood community safety interventions and hospital injury records: a multilevel study. *J Epidemiol Community Health*.	How does safety measures in overall municipal, preschool, school, and recreational activity settings affect the risk of admiiting children and adolescents to hospital due to injury?	Stockholm County, Sweden	Incidence study	1056064 person-years. Two levels: individual/family and community (N=25).	1-15	NR	Secondary data; 1995-1999 children's injuries records obtained from the Hospital Discharge Register. Each child was followed for one year.	Municipalities with each having an average population of 40,000 inhabitants. Stockholm city was excluded because of its large population size.
3	Kendrick, Mulvaney, Burton, & Watson. 2005.	Relationships between child, family and neighborhood characteristics and childhood injury: A cohort study. *Soc Sci Med*.	How are child, family, and neighborhood characteristics associated with childhood unintentional injuries that were medically attended to?	Nottingham, United Kingdom	Prospective cohort study	2357 children. Three levels: individual, family (N=1717) and electoral wards (N=70).	0-7	52.3	Primary data gathered from a cohort study that was nested in a randomized controlled trial's control arm of primary care injury prevention in children.	Electoral ward.
4	Simpson, Janssen, Craig, & Pickett. 2005.	Multilevel analysis of associations between socioeconomic status (SES) and injury among Canadian adolescents. *J Epidemiol Community Health*.	How are individual- and neighborhood-level socioeconomic variables associated with the occurrence of medically-treated, hospitalized, fighting, and sports/recreational injuries among Canadian adolescents?	Canada	Cross-sectional study	7235 students. Two levels: individual/family and school's neighborhood (N=170).	11-16 (Grade 6-10)	46.4	Secondary data; 2001/2002 Health Behavior in School-age Children survey.	5km buffer around each school attended by students who responded to the survey.
5	Pattussi, Hardy, & Sheiham. 2006.	Neighborhood social capital and dental injuries in Brazilian adolescents. *Am J Public Health*.	How is neighborhood social capital associated with dental injury?	Cities of Taguatinga and Ceilândia of Distrito Federal, Brazil	Cross-sectional study	1302 adolescents: Two levels: individual/family and school's neighborhood (N=37).	14-15	52.3	Primary data from clinical examination and self-administered questionnaire in 2002.	Enumeration districts aggregates composed of an average of about 3,535 and 13,158 households and individuals, respectively.

Table 2.1 (Continued).

Study ID	Authors and year of publication	Title and journal	Purpose of study	Country	Study design	Study population/ number of data level	Age (year)	Male (%)	Type of injury data and date of collection	Geographical extent of area level
6	Mecredy, Janssen, & Pickett. 2012.	Neighborhood street connectivity and injury in youth: a national study of built environments in Canada. *Inj Prev*.	How is street connectivity associated with injuries among Canadian youths?	Canada	Cross-sectional study	9021 students: Two levels: individual/family and school's neighborhood (N=180).	11-15 (Grade 6-10)	47.5	Secondary data; 2006 Health Behavior in School-age Children survey.	5km circular buffer around each school attended by students who responded to the survey.
7	Mutto, Lawoko, Ovuga, & Svanstrom. 2012.	Childhood and adolescent injuries in elementary schools in north-western Uganda: extent, risk and associated factors. *Int J Inj Contr Saf Promot.*	What are the extent, nature and risk factors of childhood injuries in elementary schools in north-western Uganda?	North-western Uganda	Prospective cohort study	1000 students. Two levels: individual and school (N=13).	9-16 (Grade 5)	54.5	Primary data from injury register completed by Grade-5 teachers in one school term that lasted from February 2 to April 30, 2009.	Not specified.
8	Gropp, Janssen & Pickett. 2013.	Active transportation to school in Canadian youth: should injury be a concern? *Inj Prev*.	How is active transportation to school associated with injury in Canadian youth?	Canada	Cross-sectional study	20076 students in total. Two levels: individual/family and school's neighborhood (N=419).	11-15	36.4	Secondary data; 2009/2010 Health Behavior in School-age Children survey.	1km buffer around each school attended by students who responded to the survey.
9	Byrnes, King, Hawe, Peters, Pickett & Davison. 2015.	Patterns of youth injury: a comparison across the northern territories and other parts of Canada. *Int J Circumpolar Health*.	How does injury occurrence and its potential risk factors among youths in the northern territories of Canada compare with other parts?	Canada	Cross-sectional study	26078 students in total. 3942 students attended 80 schools located in the northern territories. Two levels: individual/family and school's neighborhood (N=80).	11-15	49	Secondary data; 2009/2010 Health Behavior in School-age Children survey.	1km buffer around each school attended by students who responded to the survey.

Table 2.2: Individual and contextual measures, and main study outcomes.

Study ID	Authors and year of publication	Area-level measures	Individual/family-level measures	Main outcome measures for sports and recreational (**SRI**) injuries or total injuries including SRI.
1	Haynes, Reading & Gale. 2003.	Townsend material deprivation score, accommodation renters (%), pre-school (0-4 years) accident/injury rate, distance to playground, distance to hospital, migrants (%), 5-14 years old (%), and social cohesions indicators including: people who changed home in the past year (%), lone parents household (%), single persons household (%).	Age, sex, number of children, number of adults, and age difference between children and the oldest woman in the household.	Total injuries and serious injuries (for a 13-month period). 25% of injuries were sports related. Although the proportion of SRI were not explicitly reported, 15% of injuries were reported to have occurred at a sports/recreational facility, playground or park.
2	Sellström, Guldbrandsson, Bremberg, Hjern & Arnoldsson. 2003.	Safety index, and population density	Age, sex, maternal education, maternal birth's country, and social allowance.	Injuries that fall between E830–E929 in ICD-9 or W 01–X 59 in ICD-10 (for a 12-month period). Transportation-related injuries were excluded, and data was limited to one injury per person-year. The proportion of injuries that was due to sports and recreation activities were not reported; however, the level of safety measures in recreation activity settings were reported as one of the neighborhood-level exposure variables.
3	Kendrick, Mulvaney, Burton, & Watson. 2005.	Child poverty index, geographical access to services; distance from hospital; crime reported to police (%): dwellings experiencing domestic burglaries, population experiencing vehicle crime, population experiencing violent crime, and housing of lowest value; facilities (number/1000 children < 5 years old): nursery places, child minder places, parks and play areas, and leisure centers; road safety measures (number/1000 children < 5 years old): school crossing patrols, zebra crossings, pedestrian controlled lights, small areas of traffic calming, and large areas of traffic calming.	1) Child-level characteristics: Age, and sex. 2) Family-level characteristics: teenage motherhood; 4 or more children under age 16 in family; single parent family; rented accommodation; number of unemployed parents; car ownership; receives means tested benefits; and safety practices: fitted stair gates, fitted and working smoke alarms, and safe storage of sharp objects in kitchen.	Primary care attendance, accident and emergency department attendance, and hospital admission rates for unintentional injuries (for a two-year follow-up period).
4	Simpson, Janssen, Craig, & Pickett. 2005.	Lone parent families (%), unemployment (%), residents with less high school education (%), and average employment income.	Age, sex, family affluence, poverty, local area safety's perception, residential area's perception, and perceived family wealth.	Any medically-treated injury, hospitalized injury, sports/recreational injury, and fighting injury (for 12 months preceding the survey). 58.4% of medically treated injury were sports/recreation-related.
5	Pattussi, Hardy, & Sheiham. 2006.	Social capital, infrastructure, and poverty gap.	Age, incisal overjet, lip coverage, body mass index (BMI), and social class.	Prevalence of dental injuries in boys and girls. Sports were reported to cause 13.3% of the dental injuries while playing caused 48.1% of the dental injuries.

Table 2.2 (Continued).

Study ID	Authors and year of publication	Area-level measures	Individual/family-level measures	Main outcome measures for sports and recreation- related (SR) injuries or total injuries including SR injuries.
6	Mecredy, Janssen, & Pickett. 2012.	Street connectivity, socioeconomic status, urban-rural geographic location, and parks/recreational facilities.	Gender, grade, family affluence, perceived neighborhood safety, and perceived neighborhood aesthetics.	Any medically-treated street injury (for 12 months preceding the survey). Street injury includes those that occurred in the street/road/parking lot and during a physical activity.
7	Mutto, Lawoko, Ovuga, & Svanstrom. 2012.	School, urban-rural location, schools' religious affiliation.	Age, and sex.	School-related injuries. 35% of injuries occurred on playgrounds. 32.5% of injuries occurred during sporting activities while 12.5% occurred while walking.
8	Gropp, Janssen & Pickett. 2013.	Urban/rural geographic status, average precipitation levels, total road lengths, street or road connectivity, speed limits within 1 km buffer of each school, and population estimates of median household income for 2006.	Age, gender, ethnicity, perceived family socioeconomic status, perceived residential neighborhood safety and participation in organized sports.	Active transportation injuries (which includes both walking/running and bicycling injuries), walking/running injuries, and bicycling injuries (for a 12-month period).
9	Byrnes, King, Hawe, Peters, Pickett & Davison. 2015.	Population size, Aboriginal composition (%), permanent road access, Dwellings requiring major repair (%), alcohol policy in 2008.	Sex, school grade, ethnicity, relative family affluence, impaired driving as passenger or driver in the past 30 days, helmet's use when riding motorized vehicles in the last 12 months, alcohol use, organized sports participation.	Any injury (for a 12-month period). 23.5% of injuries among northern youths were SRI. Only walking/running injury was reported for recreation-related injuries. 11.9% of injuries in northern territories occurred at a sports facility/field.

Table 2.3: Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies by the National Institute of Health (NIH).

	Criteria	Study ID								
		1	2	3	4	5	6	7	8	9
1	Was the research question or objective in this paper clearly stated?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Was the study population clearly specified and defined?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Was the participation rate of eligible persons at least 50%?	NR	Yes	Yes	NR	Yes	Yes	NR	NR	NR
4	Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Was a sample size justification, power description, or variance and effect estimates provided?	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No
6	For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	No	No	Yes	No	No	No	Yes	No	No
7	Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	No	No	Yes	No	No	No	Yes	No	No
8	For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA
9	Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	No	No	No	No	No	No	No	No	No
10	Was the exposure(s) assessed more than once over time?	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Yes	Yes	Yes	No	Yes	No	No	No	No
12	Were the outcome assessors blinded to the exposure status of participants?	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	Was loss to follow-up after baseline 20% or less?	NA	NA	NR	NA	NA	NA	Yes	NA	NA
14	Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15	Was enough information provided to know that the appropriate multilevel technique/approach had been used and appropriately applied?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Total Score	7	9	11	6	9	7	10	7	5

*CD cannot determine; NA, not applicable; NR, not reported.

2.3.3 Multilevel analysis assessment

Among the nine studies included in our systematic review, only three assessed and reported the variance in SRI or any injuries due to neighborhood-level differences for the null or unconditional model(s) [7,15,30] (**Table 2.4**). Among the three that reported the variance in neighborhood-level differences, only two reported the statistical significance of the variance, the intraclass correlation coefficient (**ICC)** or the variance partition coefficient (**VPC**) in order to justify the use of multilevel analysis [7,15]. Of the nine studies included in the review, only two evaluated and reported the variance in individual slopes (random effects) [17,29] while another two tested for cross-level interactions between individual-level and neighborhood-level exposure variables in order to account for the individual slope variances where they existed [27,31]; however, these two studies failed to report if there was variance between individual slopes. Five studies of those included in the review assessed or reported about the unexplained variance at neighborhood-level or the proportion of variance explained by the neighborhood-level variables for the final multilevel model(s) [7,27,29–31].

2.3.4 Key findings

The estimated effects of neighborhood-level factors on SRI (and additional injuries) are summarized in **Table 2.5**. Among the nine studies included in this systematic review, only three examined SRI as an outcome or one of the outcome variables [15–17], while the others focused on a broader category of injury as outcome variable with sports and recreational activities or facilities included in the multilevel model as an exposure variable or with sports and recreational activities or facilities reported as a main cause of injury.

Lower neighborhood income was found to be associated with reduced risk of SRI among adolescents with the odds of having SRI 20% lower in neighborhood with medium average income and 19% lower in neighborhood with high average income compared to those with very high average income [17].

Lower street connectivity was found to be associated with increased risk of biking/cycling injuries among adolescents with the relative odds of being injured while biking/cycling in the street more than two times greater in neighborhoods with low street connectivity versus those with high street connectivity [16].

Among adolescents, having more parks and recreational facilities in a neighborhood was not always associated with an increased risk of street injury while playing among adolescents [16]. For example, divide all neighborhoods into five equal groups by how many parks and recreational facilities are available. Each group includes enough neighborhoods to represent 20% of all parks and recreational facilities. We would not find a statistically significant difference in the relative odds of adolescents being injured in the street when comparing the neighborhoods with the most parks/recreational facilities (top 60% vs bottom 20%). However, if we compare only the bottom two groups of neighborhoods (those with the fewest parks), we find that adolescents living in the neighborhoods in the next to bottom group actually have 69% greater relative odds of being injured while playing in the street than adolescents in neighborhoods with the least amount of parks/recreational facilities.

Finally, it was found that living or attending schools in urban communities resulted in a 1.64-fold increase in the relative odds of active transportation injury in students compared to living in rural communities [15].

Table 2.4: Summary of statistical approach of included studies.

Study ID	Authors and Year of Publication	Was variance in SRI (or any injury) due to neighborhood-level differences assessed or reported for unconditional or null model(s) to justify the use of multilevel model?	Was variance in individual slopes (random effects) evaluated or reported and was cross-level interaction tested for to account for the variance where it existed?	Was the unexplained variance at neighborhood-level or the proportion of variance explained by the neighborhood-level variables assessed or reported for the final multilevel model(s)?	Model-building process employed to develop final model(s).	Multilevel modeling type and software used.
1	Haynes, Reading, Gale. 2003.	Yes. Unexplained variance for the null or unconditional models were reported and tested for significance; however, ICCs were not reported.	No	Yes. The unexplained variances at both the enumeration district and social area levels were reported.	A single multilevel model was developed; however, several variations of multilevel models (including null model, single level, and different combinations of two- and three-level models) were developed to assess the unexplained variance in models.	Multilevel logistic regression using MLwiN software package.
2	Sellström, Guldbrandsson, Bremberg, Hjern & Arnoldsson. 2003.	No	No, variance in individual slopes was not evaluated or reported. But cross-level interactions were tested for. Interaction terms were, however, excluded from final models because they were not statistically significant.	Yes.	Three multilevel models of increasing complexities were developed to adjust for potential confounders.	Multilevel logistic regression using SAS makro Glimmix software package.
3	Kendrick, Mulvaney, Burton, & Watson. 2005.	No	Yes. Two-way interactions were examined where it appeared they might exist; however, it is not stated if the interactions included cross-level interactions.	Yes	A forward selection approach was used.	Multilevel poisson regression using MLwiN software package.
4	Simpson, Janssen, Craig, & Pickett. 2005.	No	Yes, it was reported that there was no significant variation in the slopes of the relationship between each socioeconomic variables and medically-treated injury across neighborhoods. For other injury outcomes, the variation in slopes were therefore assumed to be non-significant.	No	A two-step process was employed which include: 1) fitting bivariate models, and 2) fitting multivariable multilevel models from significant socioeconomic exposure variables in the bivariate models. Age and sex were included in all multilevel models.	Multilevel logistic regression using MLwiN software package.
5	Pattussi, Hardy, & Sheiham. 2006.	Not clear. It appears that a null model may have been fitted based on descriptive results of between-neighborhood variation in dental injuries; however, this was not clearly reported.	No, variance in individual slopes was not reported. However, results of the sex-stratified multilevel models mean that cross-level interactions were tested for between sex and neighborhood-level variables.	Yes, the variance explained by neighborhood-level variable was assessed based on the report that most of the between-neighborhood variation in dental injuries was explained by social capital; however, no numerical value of the proportion of variance explained was reported.	Four series of pre-determined multilevel models were developed including final models containing both individual and neighborhood-level predictor variables.	Multilevel logistic regression using MLwiN software package.

Table 2.4 (Continued).

Study ID	Authors and Year of Publication	Was variance in SRI (or any injury) due to neighborhood-level differences assessed or reported for unconditional or null model(s) to justify the use of multilevel model?	Was variance in individual slopes (random effects) evaluated or reported and was cross-level interaction tested for to account for the variance where it existed?	Was the unexplained variance at neighborhood-level or the proportion of variance explained by the neighborhood-level variables assessed or reported for the final multilevel model(s)?	Model-building process employed to develop final model(s).	Multilevel modeling type and software used.
6	Mecredy, Janssen, & Pickett. 2012.	No	No	No	Three series of pre-determined multilevel models were developed including a final model for total street injuries that contained both individual- and neighborhood-level predictors fitted using a backward elimination multilevel regression method. Predictor variables in the final reduced multilevel model were also then used to develop four physical activity-specific injury multilevel models.	Multilevel logistic regression using SAS Glimmix procedure.
7	Mutto, Lawoko, Ovuga, & Svanstrom. 2012.	Variance due to neighborhood level was reported for the null model; however, statistical significance of the variance, and/or the variance partition coefficient (VPC) for the model was not reported to justify the use of a multilevel model.	No	Yes, the neighborhood level variance and the proportional change in variance (PCV) explained by the final model was reported.	Four series of pre-determined multilevel models were developed including a null model, and final model that included both individual and neighorhood-level predictor variables.	Multilevel logistic regression using STATA.
8	Gropp, Janssen & Pickett. 2013.	Yes. Intraclass correlation coefficient (ICC) was reported.	No	No	A backward elimination approach was used to select statistically significant individual and area-level predictor variables.	Multilevel logistic regression using SAS software package.
9	Byrnes, King, Hawe, Peters, Pickett & Davison. 2015.	No	No	No	A backward elimination approach was used but sex, grade, and relative family affluence were retained in the final model based on a priori decision.	Multilevel, multivariable, log binomial regression model was used to analyze risk of injury among northern youths only. Modeling was carried out with SAS software package.

Table 2.5: Statistically significant ($p < 0.05$) neighborhood-level effects in final multilevel models for included studies.

Study ID	Authors and year of publication	Estimated effects of significant neighborhood-level variables on SRI or total injuries including SRI in final multilevel model(s)	Summary of study's main findings
1	Haynes, Reading, Gale. 2003.	Social area material deprivation was positively correlated with the risk of all injuries and serious injuries. The risk of all injuries and serious injuries increased by 4% for each unit increase in Townsend material deprivation score (OR$_{all}$=1.04, 95%CI=1.02-1.06; OR$_{serious}$=1.04, 95%CI=1.02-1.07).	Neighborhood material deprivation increased the risk of all injuries and serious injuries.
2	Sellström, Guldbrandsson, Bremberg, Hjern & Arnoldsson. 2003.	Few and average level of safety measures (lower safety index) were positively associated with higher hospital admissions rate for injuries in preschool-aged children. The odds of being admitted for injuries were greater by 20% (RR$_{average}$=1.20, 95%CI=1.05-1.36) and 33% (RR$_{few}$=1.33, 95%CI=1.15-1.49) in municipalities with average and few safety measures, respectively, compared with those with many safety measures. In school-aged children, positive association was also observed between lower safety index and hospital admissions rate; however, the relationships were not statistically significant.	Lower level of safety measures increased the risk of injuries for preschool-aged children.
3	Kendrick, Mulvaney, Burton, & Watson. 2005.	1) Primary care attendance rates for injuries were 2.4 (RR=2.41, 95%CI=1.34-4.34) and 1.9 (RR=1.92, 95%CI=1.04-3.52) times greater in children living in the 3rd and 4th deprived quintile of wards per geographical access to services, respectively, than those living in the least deprived quintile of wards. However, the attendance rates for injuries were not significantly greater in children living in the 2nd (RR=1.22, 95%CI=0.65-2.29) and most deprived (5th) quintile (RR=1.65, 95%CI=0.90-3.03) of wards.	1) The relationship between neighborhood access to health care services and primary care attendance rates for injuries in children was n-shaped.
		2) Accident and Emergency Department attendance rate for injuries (in model that included rented accommodation) increased by 2% for each additional increase in the parks and play areas per 1000 children < age 5 (RR=1.02, 95%CI=1.00-1.04).	2) The rates of visiting Accident and Emergency Departments for injuries increased with higher number of parks and play areas in wards.
		3) Hospital admission rates for injuries in model that included fitted stairgate were 5.2 (RR=5.21, 95%CI=1.52-17.90) and 4.5 (RR=4.50, 95%CI=1.32-15.40) times greater in children living in the 2nd and most deprived quarter of wards per child poverty index, respectively, than those living in the least deprived quarter of wards. Also, hospital admission rates for injuries in model that included smoke alarm were 7.0 (RR=7.04, 95%CI=2.07-23.94), 4.2 (OR=4.23, 95%CI=1.16-15.40) and 4.1 (RR=4.13, 95%CI=1.17-14.64) times greater in children living in the 2nd, 3rd, and most deprived quarter of wards per child poverty index, respectively, than those living in the least deprived quarter of wards. In addition, hospital admission rates for injuries in the fitted stairgate model increased by 14% (RR=1.14, 95%CI=1.03-1.27) for every percent increase in population experiencing violent crimes.	3) Hospital admission rates for injuries were higher in wards with higher child poverty index than those with lower index. Also, admission rates were higher in wards where a greater proportion of the population were experiencing violent crimes.
4	Simpson, Janssen, Craig, & Pickett. 2005.	1) The odds of being hospitalized for injuries was 64% greater in schools' neighborhood with high (OR=1.64, 95%CI=1.04-2.61) and very high (OR=1.64, 95%CI=1.05-2.56) percentages of lone parent families compared with those with low percentage. Also, the odds of hospitalization for injuries was more than 2 times greater in schools' neighborhood with a very high percentage of population with less than a high school education compared with those with low percentage (OR=2.11, 95%CI=1.36-3.28).	Lower socioeconomic status increased the risk of injury hospitalization.
		2) The odds of having sports/recreational injury were 20% (OR=0.80, 95%CI=0.67-0.96) and 19% (OR=0.81, 95%CI=0.68-0.97) lower in schools' neighborhood with medium and high average employment income, respectively, than those with very high average employment income.	Higher socioeconomic status was associated with increased risk of sports/recreational injury among adolescents.
5	Pattussi, Hardy, & Sheiham. 2006.	The odds of having dental injuries in boys decreased by 45% (OR=0.55, 95%CI=0.32-0.81) per unit increase in neighborhood social capital index. The relationship was not significant in girls.	Higher social capital index was protective against dental injuries in boys but not girls.
6	Mecredy, Janssen, & Pickett. 2012.	1) The relative odds of being injured while playing in the street was not significantly greater in children living in neighborhoods with the highest, second to highest, and third to the highest quintile of parks/recreational facilities versus those living in neighborhoods with the lowest quintile. However, the relative odds of street injury was 69% greater in children living in neighborhoods with second to the lowest quintile of parks/recreational facilities (OR=1.69, 95%CI=1.05-2.71) versus those living in neighborhoods with the lowest quintile.	Increased number of parks and recreational facilities was not associated with increased risk of street injury while playing.
		2) The relative odds of being injured while biking/cycling in the street was more than two times greater in neighborhoods with low street connectivity (OR=2.33, 95%CI=1.28-4.25) versus those with high street connectivity.	Lower street connectivity was associated with increased risk of biking/cycling injuries.

Table 2.5 (Continued).

Study ID	Authors and year of publication	Estimated effects of significant neighborhood-level variables on SRI or total injuries including SRI in final multilevel model(s)	Summary of study's main findings
7	Mutto, Lawoko, Ovuga, & Svanstrom. 2012.	The odds of being injured was about 4 times (OR=4.08, 95%CI=1.12-18.67) and 7 times (OR=6.85, 95%CI=1.42-33.15) greater for students attending school in urban and peri-urban locations, respectively, than those attending school in rural location.	Schools situated in urban and peri- locations increased risk of childho adolescent injuries when compare situated in rural locations.
8	Gropp, Janssen & Pickett. 2013.	Urban community status resulted in 1.64-fold increase in the relative odds of active transportation injury for students compared to rural community status (OR=1.64, 95%CI=1.14-2.36). Results of the association between neighborhood-level factors and walking/running and bicycling injuries were not reported.	Living or attending schools in urba communities increased the risk of transportation injuries for students
9	Byrnes, King, Hawe, Peters, Pickett & Davison. 2015.	Lack of permanent road access lowered the risk of injury by 11% (RR=0.89, 95%CI=0.80-0.98).	Lack of access to road was protect injury.

2.4 Discussion

Our findings suggest that more effort should be made to capture information on SRI and neighborhood characteristics when capturing data on individual-level health behaviors and outcomes. This will make it possible for more studies to examine the simultaneous effects of individual-level and neighborhood-level exposures on SRI risks. Of the nine studies reviewed, only three examined SRI as the main outcome or one of the main outcomes [15–17], suggesting a limited understanding of the direct and indirect role of neighborhood characteristics on SRI risk. Results from these few studies show that higher socioeconomic context (i.e., higher average employment income [17]), lower street connectivity [16], and living or attending schools in urban communities [15] were associated with increased risk of SRI after adjusting for individual-level and other neighborhood-level risk factors for SRI.

Most of the neighborhood factors associated with increased risk of SRI in the studies we reviewed are factors that have been shown to increase physical activity. For instance, a systematic review by An et al. reported that the availability of recreational facilities was positively associated with physical activity [33]. Another systematic review found in some studies that children living in poorer neighborhoods showed lower level of physical activity compared to those living in wealthier neighborhoods [34]. Lower levels of physical activity have also been reported in rural areas compared to urban areas [35]. For neighborhood street connectivity, a systematic review observed in most studies reviewed that higher neighborhood street connectivity was associated with higher level of physical activity [36]. This report about street connectivity and physical activity in combination with the observed relationship with SRI that we found for studies in this review suggests that higher neighborhood street connectivity can both increase physical activity and protect against SRI in children. Findings from this review provide information on neighborhood environments where proper safety precautions should be taken by participants of sports and recreational activity to protect themselves against injuries while maintaining or increasing their physical activity level. Adequate safety measures should be put in neighborhood environments, such as streets with lower connectivity and urban areas, to prevent SRI.

Results of how injuries in general are associated with neighborhood socioeconomic context is mostly different from what we found for SRI. For example, Haynes at al. found that neighborhood material deprivation increased the risk of all injuries in children presented at hospital Emergency Department in the city of Norwich, UK [7] (**Table 2.5**). Also, Kendrick at al. and Simpson et. al. reported that injury hospitalization were higher in deprived neighborhoods than in affluent neighborhoods in Nottingham, UK and in Canada, respectively [17,29] (**Table 2.5**). Because SRI risks increase with increasing physical activity levels, neighborhood environments that enhances physical activity, such as affluent neighborhoods with better quality sidewalks and bike lanes, may increase the risks of SRI while generally reducing the risks of all other injuries. The higher risk of SRI in urban areas versus rural areas could be because of the greater presence of physical activity-promoting resources, such as parks and recreational facilities, walking trails, sidewalks, bike lanes, improved street connectivity, street lighting, easy and safe street crossings, traffic calming, street beautification, mixed land use zoning, transit-oriented development etc., in urban areas compared to rural areas. The higher socioeconomic status of many residents of urban areas compared to residents of rural areas could also explain the higher risks of SRI among urban residents since higher socioeconomic status is often associated with higher risks of SRI while generally lowering the risks of other injuries. Our finding supports the significance of studying the different types of injuries (e.g., SRI) separately to identify their individual relationships with neighborhood socioeconomic context. This will help in developing the right prevention intervention for the neighborhood environment associated with higher risks of each injury type.

While this study screened articles that examined people of all age groups, all nine studies that were selected for review focused on only children and adolescent population, suggesting the need for studies that assess the multilevel effects of individual and neighborhood characteristics on the risk of unintentional injuries among adult populations. Also, all the three studies that assessed the multilevel risk factors for SRI were focused only on Canadian children and adolescents with studies lacking in other developed and developing countries [15–17]. To know if the relationships observed in Canada hold true elsewhere, other studies need to examine populations in other parts of the world.

In addition to the observed limitations related to the study population in the reviewed articles, we observed limitations in their study design. All reviewed studies used observational study design which made it difficult to determine if there was a causal relationship between neighborhood characteristics and SRI risk. Considering that experimental studies, which make it possible to determine causality in relationships, is not feasible in many instances, researchers should identify possibilities of using quasi-experimental designs because of their higher internal validity when compared to observational study designs [21]. Also, all three studies that focused on SRI as outcome employed cross-sectional study design, making it impossible to assess changes in SRI rates in response to changes in neighborhood environment.

The quality assessment ratings of the reviewed studies were not correlated with the quality of information reported for the multilevel models. For example, most of the reviewed studies, including those with very high-quality ratings, did not provide the necessary report to justify their use of multilevel models. Only one study reported about intraclass correlation coefficient (**ICC**) or variance partition coefficient (**VPC**) for the null model [15], an estimate that allows for the quantification of the proportion of total variance in injuries that is attributable to neighborhood-level differences. Two other studies reported about the variance due to neighborhood-level differences for the null model with one testing for the statistical significance of the unexplained variance [7,30]; however, they both did not report the ICC or VPC for the null model. Report on the ICC or VPC for the null model helps to assess if the need exists to use a multilevel model rather than a classical regression model [19]. Higher ICC or VPC justifies the use of multilevel models because it indicates that the proportion of total variance in injuries that is attributable to neighborhood-level differences is high and, therefore a model that includes neighborhood-level factors to explain the existing variance is needed. Also, only two studies out of the nine studies reviewed reported about random effects for the multilevel models [17,29]. Another two studies tested for cross-level interaction even though reports of random effects were not provided [27,31]. The presence of significant random effects provide justification to test for cross-level interaction (CLI). Therefore, by not reporting or testing for random effects, these studies failed to provide a justification to test for CLI. In addition, only about half of reviewed studies reported the unexplained variance or the proportion of variance explained by the neighborhood-level factors for the final multilevel models, thereby limiting our understanding of the strength of neighborhood-level factors in explaining the variation in SRI.

Multilevel models can help us understand the direct, indirect, or interactive effects of neighborhood-level risk factors on SR injuries. For example, it is possible that neighborhood-built environment, a direct risk factor for SR injuries, can modify or moderate the relationship between individual socioeconomic status and SR injury risks. However, failure to test for CLIs limit our understanding of these important relationships. To increase understanding of the multilevel determinants of injuries, there is the need for consistency in how statistical analysis are carried out and how results of studies are reported [20].

2.4.1 Limitations

The literature search strategy used in our review restricted our search results to peer review articles published in English language only. As a result, articles published in other languages and gray literature may have been excluded from our study. However, considering the significant number of peer review studies published in English language and the low number of articles that were eligible for this review, the chances of excluding additional articles published in other languages and gray literature are slim.

2.4.2 Future Study Directions

Future studies on the multilevel effects of neighborhood on SRI should be carried out in countries where studies are currently missing such as the United States and low- and medium-income countries (**LMIC**). While capturing contextual level information might be a challenge in many LMIC, this is not the case in the United States and many other developed countries since this information has been captured in many primary and secondary data studies for other health outcomes and behaviors (e.g., physical activity and obesity) [37–39]. The reason for the lack of studies in the United States, for example, is likely due to the fact that many primary and secondary data capturing information on health behaviors and outcomes do not capture information on SRI and those that capture information on individual SRI risk often fail to capture contextual level information. This mean that researchers who wants to assess the association between neighborhood context and SRI might be required to apply more complex methods such as data linkage and analysis of nested or hierarchical data. For researcher who need to collect primary data, contextual level information can be collected by self-administered questionnaires or telephone interviews, by neighborhood audits, and by GIS-based measures that are derived from existing data sources with spatial reference [40].

Only two of the studies we reviewed were carried out in LMIC [27,30], indicating that more future studies should investigate the effect of neighborhood on SRI in LMIC and do comparative analyses of the relationships in LMIC versus developed countries. Future studies should also investigate how other neighborhood variables that enhance walkability or bikeability are associated with SRI. Two of the reviewed studies that examined neighborhood effect on SRI assessed the relationship between neighborhood street connectivity and SRI [15,16]. While street network connectivity may be an indicator that a neighborhood is walkable or bikeable, other neighborhood variables, such as the presence and quality of sidewalks and bike lanes or a composite score of the density of neighborhood attributes of interest, diversity of land use, street design, and accessibility to destination of interest, may be better indicators of neighborhood walkability [41]. Also, the effects of historic and present-day neighborhood segregation and social vulnerability (factors that weaken a neighborhood's ability to respond to hazardous events such as injury [42]) on SRI should be examined as these factors have been found to be associated with other health outcomes and health behaviors including physical inactivity and obesity [43–46].

2.5 Conclusion

This review systematically analyzed studies that applied multilevel models to assess the effects of neighborhood-level risk factors on SRI. Only nine studies met our eligibility criteria for inclusion in this review and among them only three examined SRI as the main outcome or one of the main outcomes. These studies showed that neighborhood-level factors, such as higher socioeconomic context, lower street connectivity, and living or attending schools in urban communities, were associated with increased risk of SRI. While these findings provide evidence that neighborhood-level factors in addition to individual-level factors should be taken into consideration when developing public health policies for injury prevention, more multilevel studies should be carried to strengthen this evidence in order to better inform SRI prevention policy decisions. Four quality assessment criteria out of 15 were met by all nine studies including clearly specifying and defining the study population, selecting study subjects from similar population at same time period, pre-specifying and uniformly applying inclusion and exclusion criteria for all study participants, and adjusting for key confounding variables. However, only a few studies provided report of study participation rate of ≥ 50% for eligible persons (n = 4), measured exposures of interest prior to measuring study outcomes (n = 2), and had sufficient timeline to increase the probability of finding significant association between exposure and outcome if it existed (n = 2). None of the studies used experimental or quasi-experimental design. Future studies should identify possibilities of using experimental or quasi-experimental designs so that they can easily determine if there is a causal relationship between neighborhood characteristics and SRI risk. Also, longitudinal studies should be explored so that changes in SRI rates in response to changes in neighborhood environment can be assessed. Future studies should also provide a more coherent report of the results of multilevel models, one that presents estimates that help to 1) justify the use of multilevel models, 2) justify the test for cross-level interactions when examined, 3) determine the strength of neighborhood-level factors in explaining the variation in SRI which will help to provide a better understanding of the impact of neighborhood characteristics on SRI risk.

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Chapter 3: Historical Redlining and Current Neighborhood Social Vulnerability in the United States

Abstract

Background: In this study, we examined the association between historical redlining, a government-sanctioned racial discriminatory practice of the 1930s, and present-day neighborhood social vulnerability in the U.S.

Methods: We obtained the 2018 social vulnerability index (SVI) data from the U.S. Centers for Disease Control and Prevention, linked it to 1930s Home Owners' Loan Corporation (HOLC) redlining maps, and assigned U.S. neighborhoods to one of four HOLC grades ("A: best", "B: still desirable", "C: definitely declining", and "D: hazardous/redlined").

Results: Using multilevel models, we found significant association between historical HOLC redlining grades of neighborhoods and present-day overall, socioeconomic, minority status, household composition, and housing type/transportation vulnerability. Neighborhoods formerly assigned less favorable grades by the HOLC in the 1930s showed significantly greater vulnerability presently than those that were graded more favorably (i.e., "D" > "C" > "B" > "A" in SVI). For instance, neighborhoods that were formerly graded "B: still desirable", "C: definitely declining", and "D: hazardous/redlined" were 0.068-, 0.107-, and 0.114-unit greater in present-day overall SVI score, respectively, than neighborhoods previously graded "A: best" (mean score of 0.477). Also, we found that the relationship between HOLC security grades and all present-day neighborhood SVI, except household composition SVI, varied by city.

Conclusion: This study indicates that historical redlining, an indicator of structural racism, has a lasting impact on neighborhood social vulnerability.

Keywords: redlining, social vulnerability, structural racism, neighborhood, city

3.1 Background

Neighborhood socioeconomic and environmental inequalities are major predictors of health inequalities in US cities.[1] Neighborhood inequality is the product of historic and present-day neighborhood segregation and disinvestment.[2] Concentrated disadvantage and poverty resulting from segregation and disinvestment can make a neighborhood socially vulnerable to the impact of diseases, injuries, and disaster. Social vulnerability refers to factors that weaken a community's resilience (ability to survive and thrive) to external stresses on human health[3]. Such stresses include disease outbreaks, injury, natural or human-caused disaster.[3] Many factors influence the social vulnerability of a population and these include gender, race, ethnicity, age, socioeconomic status, disability, transportation access and medical services.[4–7]

Public health researchers have developed tools to help public health officials and emergency response planners identify and map socially vulnerable communities before, during, and after an emergency.[4,6] One of these tools was developed by the Geospatial Research, Analysis and Services Program (**GRASP**) at the Centers for Disease Prevention and Control and Agency for Toxic Substances and Disease Registry (i.e., the **CDC/ATSDR** Social Vulnerability Index or **SVI**) and it captures overall as well as theme-specific SVI, including socioeconomic, minority status/language, household composition/disability, and housing type/transportation SVI. An increasing number of studies have reported associations between neighborhood social vulnerability and the incidence or prevalence of infectious and chronic diseases, obesity, physical inactivity, teen pregnancy, poorer healthcare quality, and mortality from adverse health outcomes.[8,9,18–20,10–17]

Recent studies have found that individual factors that influence the social vulnerability of communities or neighborhoods are associated with historical racial residential segregation in the

US.[1,21–27] Findings from these studies show that present-day neighborhoods that were historically segregated continue to have more racial/ethnic minorities and more people living below poverty level compared to neighborhoods that were not formerly marginalized. Historical residential segregation policies were implemented through different measures, including racially-restrictive deed covenants, zoning regulations, as well as government-implemented "redlining".[2,28]

Historical redlining refers to the discriminatory practice started in the 1930s that denied access to loans in neighborhoods with high racial, ethnic, and/or low-income populations.[28] The Home Owners' Loan Corporation (**HOLC**), a federal agency, was established in 1933 as part of the New Deal to help stabilize the real estate market during the Great Depression by both helping existing home loan borrowers refinance and creating opportunities for new borrowers. The HOLC created maps to determine credibility in borrowing and repaying home loans (mortgage risk) in U.S. urban areas.[1,2,28] Neighborhoods were graded by color based on perceived risk of investing in them [Grade A – green ("best"), Grade B – blue ("still desirable"), Grade C – yellow ("definitely declining"), and Grade D – red ("hazardous")].[2,28] Neighborhood assessments were based mainly on the demographics of neighborhood residents and the physical condition of homes, though other criteria such as access to transportation, presence of industrial facilities, and amenities such as sidewalks and grocery stores were also part of the grading system.[2,28] Neighborhoods that were mostly white U.S.-born white collar residents and that have newer homes were often graded as "A: best" or "B: still desirable" in terms of risk of investment. Neighborhoods that consisted mostly of non-white residents (especially Black residents), immigrants, blue-collar workers, and older homes were often graded as "C: definitely declining" or "D: hazardous or redlined".[2,28] Redlined neighborhoods experienced disinvestment and concentrated disadvantage based on these maps and the perceived lack of creditworthiness.[28] The disinvestment meant that redlined neighborhoods were often excluded from city works improvements (sidewalks, roads, water and sewage pipes, green projects such as tree planting, better transportation) and the same types of business developments that were funded in non-redlined areas.[1,29–33] Though the HOLC ceased operations in 1951, the structural segregation it reinforced did not. Redlining and the resulting concentration of disadvantage may continue to impact health through “poor housing conditions, disparities in educational and employment opportunities, inadequate transportation infrastructure, access to healthcare, and economic instability.”[34]

Recent studies have found an association between historical redlining and present-day poor health outcomes and behaviors.[21–24,26,28,35] This indicates that structural racism created circumstances of concentrated disadvantage and poverty for individuals living in redlined neighborhoods, manifesting in residents being exposed to fewer health-promoting resources and opportunities (e.g., access to quality food, healthcare, and parks and recreational facilities), and more health-damaging threats (e.g., poor housing quality, and environmental pollution).[34] Richardson at al. (2020) found that one-unit increase in historical redlining score was associated with a 0.15 unit increase in neighborhood overall SVI in the US;[28] however, they did not investigate whether redlining have differential impact on theme-specific social vulnerability such as socioeconomic SVI, minority status SVI, household composition SVI, and housing type/transportation SVI. They also did not examine if these relationships vary across cities.

Considering that several individual factors that influence present-day neighborhood social vulnerability are associated with historical redlining, and that neighborhoods with higher social vulnerability and/or those that were redlined are associated with poorer health outcomes and behaviors, we hypothesize that neighborhoods that were redlined will have higher overall, socioeconomic, minority status/language, household composition/disability, and housing type/transportation vulnerability. Because local governments (e.g., city governments) often have a huge influence over neighborhood development, housing, zoning and land use, and socioeconomic opportunities,[23] we also hypothesize that the association between historical redlining and present-day neighborhood social vulnerability will vary across cities.

Therefore, the main objectives of this study are: 1) to determine whether historical redlining is associated with present-day neighborhood social vulnerability (overall and theme-specific); and 2) to determine whether the influence of historical redlining on present-day neighborhood social vulnerability varies across cities.

3.2 Methods

3.2.1 Study area and data collection

Nationwide data of the 1930's HOLC residential security maps that were digitized by a team at the University of Richmond, University of Maryland, John Hopkins, and Virginia Tech were obtained for analysis.[36] The maps are part of the "Mapping Inequality: Redlining in New Deal America" project which involves georectification and digitization of HOLC maps of cities across the U.S.[36] We also obtained the 2018 nationwide CDC/ATSDR SVI census tract shapefiles from the U.S. CDC's website.[37] In addition, we obtained the 1940 and 2018 census tract shapefiles from the U.S. Census and sociodemographic data from the Integrated Public Use Microdata Series (**IPUMS**) National Historical Geographic Information System database (**NHGIS**).[38] The 1940 U.S. Census data was available at the census tract level and was available for only 60 cities, comprising more than one-fourth of the U.S. population at that time.[39]

3.2.2 HOLC neighborhood polygons

Digitized maps consisting of 8,878 HOLC defined neighborhood boundaries (or polygons) of 196 cities and 38 states were available for analysis as of June 11, 2021. Some of the HOLC neighborhood boundaries were located outside of the 1940 census tract areas of the 60 cities for which tract data were available, and those that were not outside the census tract boundaries were often overlapped by more than one census tract. In order to assign 1940 census metrics to the HOLC neighborhood polygons, we used the method of Nardone et al which involved overlaying the 1940 census tract polygons with the HOLC neighborhood polygons using ArcGIS Pro[40] and then using areal apportionment to generate areal-weighted census measures for each HOLC neighborhood polygons that overlapped with the 1940 census tracts boundaries.[21] Four HOLC neighborhood polygons were graded E. Because the meaning of E was not clear, we excluded these polygons from our analysis. After excluding non-overlapping polygons, overlay areas with zero population count, and the four HOLC polygons with a grade of E, a total of 4,171 HOLC polygons across 71 urban areas and 27 states out of a total of 48 states in 1940 were available for analysis.

3.2.3 Sociodemographic variables

The neighborhood sociodemographic near the time HOLC maps were created influenced residential security grades,[1,21,41] and are associated with present-day neighborhood social vulnerability. To account for neighborhood sociodemographic during that time as potential confounders so as not to overestimate the true effect of HOLC maps,[1] we adjusted for 1940 census measures since HOLC maps were created between 1935 and 1940.[28] This is in line with previous studies.**[1,21,41]** The reason for using 1940 census measures instead of 1930 census measures is well documented by Jacoby et al. (2018), Nardone et al. (2020), and Nardone et al. (2021).[1,21,41]

Sociodemographic variables obtained for the 1940 Census include the number of Black, non-White, White, employed residents, residents aged 25 and above with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home.

3.2.4 Social vulnerability index (SVI)

The U.S. CDC uses census data to determine the social vulnerability of census tracts nationwide. To compute the CDC/ATSDR SVI, the CDC ranks every census tract based on 15 sociodemographic variables, including poverty, income, unemployment, lack of high school diploma, disability, presence of younger population (≤ 17 years), presence of older population (≥ 65 years), single-parent households, minority population, population with lesser English speaking proficiency, lack of vehicle access, crowded housing, persons living in group quarters, presence of multi-unit structures and mobile homes.[7] The ranking is based on percentiles, with values ranging from 0 to 1, and higher values signifying greater vulnerability. Each variable is grouped into one of four themes, including socioeconomic status, household composition and disability, minority status and language, and housing type and transportation, which are ranked separately for each census tract.[7] Also, each census tract receives an overall ranking, which we will refer to as overall SVI. Nationwide SVI data for 2018 was used for the analysis.

3.2.5 Statistical analysis

We used Analysis of Variance (ANOVA) to determine if overall SVI and individual SVI themes were different between HOLC risk grades nationwide. A Tukey honest significant difference (HSD) post-hoc test was then used to evaluate the pairwise comparison of the means for each HOLC risk grades.

We used multilevel mixed effects models to examine the relationships between HOLC risk grades and SVI (overall SVI and individual SVI themes), and whether the relationships varied across cities. Confounding neighborhood sociodemographic variables were group-mean centered ($X_{ij} - \bar{X}_{.j}$) by subtracting each city's mean of each variable from the individual values of each neighborhood variable within that city to control for differences between cities and to reduce correlation with city-level predictor variables.[42] We estimated model parameters using maximum-likelihood estimation. Statistical significance was taken at the 5% level and did not adjust for multiplicity. Analyses were carried out using the Proc Mixed procedure in SAS.[43] Our approach to the multilevel models involved three steps:

1) <u>Unconditional model:</u> First, to test whether there was significant variation in SVI among cities, we developed an unconditional model with SVI (dependent variable) varying by city (random intercept) and no independent variables. This model partitioned the total variance in SVI into within city (neighborhood variation, σ^2) and between city (τ_{00}) components. We calculated the intra-class correlation (ICC) from the variance components. The ICC quantifies the proportion of variance in SVI that is between city, and determines if there is enough variation in SVI between city to justify the use of multilevel model:

$\text{ICC} = \tau_{00} / (\tau_{00} + \sigma^2)$

2) <u>Fixed HOLC grade model:</u> After examining the ICC, we developed the second sets of candidate models for SVI that included the four-category neighborhood HOLC grades as the fixed effects, in addition to random intercepts. HOLC grade A was the reference category. The intercept estimate represents the mean SVI for HOLC grade A. The estimates for HOLC grades

B, C, and D represent the difference in mean SVI from A. These model and subsequent models were adjusted for 1940 neighborhood sociodemographic variables, including the proportion of non-White, employed residents, residents aged 25 and older with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home.

3) Fixed + random HOLC grade model: The third sets of candidate models are similar to the second sets of models, but these models included HOLC grades as fixed and random effects (i.e., HOLC grades were allowed to vary by city). These models allowed us to assess if the relationship between SVI and HOLC grades varied across cities. The relationship was considered to vary across cities if there was a significant random effect for HOLC grades and if the fit for these models was better [lower Akaike Information Criteria (**AIC**) and Bayesian Information Criteria (**BIC**) values] than the fit for the second sets of models that included HOLC grades as fixed effects only.

3.2.6 Human Subjects Review

This study did not require human subjects' approval.

3.3 Results

Results of analysis of HOLC neighborhood polygons across 71 urban areas and 27 states that spatially overlapped 1940 U.S. census tracts, 1940 sociodemographic variables, and 2018 overall and theme-specific (e.g., transportation and housing) SVI are presented in **Table 3.1**. Among 4,171 HOLC polygons, 10.7%, 25.3%, 39.5% and 24.6% were graded "A: best", "B: still desirable", "C: definitely declining", and "D: hazardous", respectively. The percentages of

Blacks and non-White residents were greatest for historically grade D neighborhoods (i.e., redlined neighborhoods). The percentage of residents who were employed and the median value of home in 1940 decreased from historically grade A to grade D neighborhoods. Similar to 1940 neighborhood socioeconomic conditions, current neighborhood social vulnerability (overall and theme-specific SVI - socioeconomic, household composition/disability, minority status/language, and housing type/transportation SVI) worsened with worsening HOLC grade.

Overall and theme-specific neighborhood social vulnerability index (**SVI**) varied between U.S. cities (**Tables 3.2-3.6**). The intraclass correlation coefficient (**ICC**) for overall SVI was 22% (**Table 3.2**), indicating that 22% of the variation in overall social vulnerability was attributable to differences between cities while 78% of the variation was attributable to differences within cities (i.e., differences between neighborhoods). For theme-specific neighborhood SVI, 29%, 32%, 42%, and 12% of the variation in socioeconomic, household composition and disability, minority status and language, and housing type and transportation vulnerability, respectively, were attributable to differences between cities; while 71%, 68%, 58%, and 88% of the variation, respectively, were attributable to differences within cities (**Tables 3.3-3.6**). The large proportion of the variability in SVI attributable to cities underscores the importance of accounting for city-level variation in SVI, in addition to neighborhood variation. Thus, we used multilevel mixed effects models for all subsequent analyses to account for the variation in SVI between cities by varying the intercept of the models (i.e., random intercept).

Table 3.1: 1940 sociodemographic, and 2018 overall and theme-specific social vulnerability index (SVI) for all Home Owners' Loan Corporation (HOLC) neighborhood polygons that overlapped 1940 U.S. census tracts in 71 U.S. urban areas.

	HOLC grade			
Characteristics	A	B	C	D
HOLC polygons [N (%)]	446 (10.7)	1053 (25.3)	1647 (39.5)	1025 (24.6)
1940 U.S. Census characteristics [mean (SD)]				
Black (%)	2.6 (6.8)	2.1 (6.7)	3.2 (8.7)	13.1 (21.6)
Non-White (%)	2.9 (6.9)	2.4 (6.7)	3.4 (8.7)	13.5 (21.6)
White (%)	97.1 (6.9)	97.6 (6.7)	96.6 (8.8)	86.5 (21.6)
Age ≥ 25 years with no high school diploma (%)	44.8 (15.2)	55.5 (15.8)	66.9 (14.9)	77.9 (12.5)
Employed (%)	93.3 (4.0)	90.9 (4.3)	87.8 (5.0)	81.1 (7.4)
Median home value (1940 US$)	7630.2 (3499.9)	5534.5 (2488.8)	4230.3 (1851.4)	2828.6 (1648.8)
Homes needing major repairs (%)	3.5 (4.4)	4.8 (4.82)	6.5 (6.1)	11.6 (9.4)
Homes without a radio (%)	2.2 (4.3)	2.7 (4.6)	3.7 (5.3)	9.5 (11.0)
Homes without a mechanical refrigerator (%)	16.5 (13.1)	22.6 (14.5)	31.7 (16.2)	51.4 (18.5)
Homes without central heating (%)	19.9 (26.3)	24.4 (28.0)	31.5 (30.1)	50.3 (31.7)
Homes with > 2 persons per room (%)	0.4 (0.9)	0.5 (1.1)	0.9 (1.4)	2.2 (3.1)
Number of persons per housing unit	3.5 (0.4)	3.5 (0.6)	3.6 (0.5)	3.7 (0.5)
Multi-unit structure (%)	7.4 (14.9)	8.4 (17.2)	9.0 (15.6)	8.9 (17.0)
2018 Social Vulnerability Index (SVI) [mean (SD)]				
Overall SVI	0.30 (0.25) ^{a}	0.46 (0.28) ^{b}	0.59 (0.26) ^{c}	0.67 (0.24) ^{d}
Socioeconomic SVI	0.28 (0.26) ^{a}	0.45 (0.29) ^{b}	0.60 (0.28) ^{c}	0.68 (0.27) ^{d}
Household composition and disability SVI	0.30 (0.24) ^{a}	0.38 (0.29) ^{b}	0.46 (0.30) ^{c}	0.51 (0.31) ^{d}
Minority status and language SVI	0.46 (0.22) ^{a}	0.56 (0.24) ^{b}	0.63 (0.23) ^{c}	0.65 (0.21) ^{c}
Housing type and transportation SVI	0.39 (0.25) ^{a}	0.49 (0.24) ^{b}	0.57 (0.22) ^{c}	0.63 (0.21) ^{d}

*****Overall and theme-specific SVI for HOLC grades with different letters are significantly different at α = 0.001. Tukey's range test was used for pairwise comparison of SVI means for each HOLC risk grades.

3.3.1 Neighborhood HOLC grade and social vulnerability

We found a significant association between HOLC grades and neighborhood SVI in the U.S. ($p < 0.05$; **Table 3.1–3.6**). Results of one-way ANOVA revealed significant differences in mean overall and theme-specific SVI between neighborhood graded differently by the HOLC in the 1930s ($p < 0.001$; **Table 3.1**). Pairwise mean comparison using Tukey HSD post-hoc test showed that neighborhoods formerly assigned less favorable grades by HOLC in the 1930s are significantly more vulnerable presently (higher SVI) than those that were graded more favorably (i.e., "D: hazardous" > "C: definitely declining" > "B: still desirable" > "A: best") [$p < 0.001$; **Table 3.1**]. All pairwise comparisons of overall and theme-specific SVI were significantly different ($p < 0.05$), with the exception of the comparison of neighborhoods formerly graded C and D for minority status/language SVI (**Table 3.1**).

The association between HOLC grades and neighborhood SVI was also examined using multilevel mixed effects models that adjusted for 1940 neighborhood sociodemographic variables (**Table 3.2–3.6**). We assessed for improvements in model fit (i.e., lower AIC and BIC values) for all our models and identified model 3 as the best-fitting model for overall SVI (**Table 3.2**), socioeconomic SVI (**Table 3.3**), minority status/language SVI (**Table 3.5**), and housing type/transportation SVI (**Table 3.6**); while model 2 was identified as the best fitting models for household composition/disability SVI (**Table 3.4**).

Results of multilevel mixed effects model indicated that neighborhoods that were previously graded less favorable showed significantly greater vulnerability than neighborhoods previously graded most favorable after adjusting for 1940 sociodemographic variables. Neighborhoods that were previously graded B, C, and D showed 0.064-, 0.105-, and 0.113-unit greater overall SVI (i.e., mean overall SVI score of 0.535, 0.576, and 0.584), respectively, than neighborhoods previously graded A (mean overall SVI score of 0.471; **Table 3.2**, Model 3). Vulnerability index score for socioeconomic condition was 0.070-, 0.114-, and 0.118-unit greater (i.e., mean index score of 0.531, 0.575, and 0.579) in neighborhoods that were previously graded B, C, and D respectively, than those previously graded A (mean index score of 0.461; **Table 3.3**, Model 3). Also, vulnerability index score for household composition/disability was 0.018-, 0.040-, and 0.049-unit greater (i.e., mean index score of 0.428, 0.450, and 0.459) in neighborhoods that were previously graded B, C, and D respectively, than those previously graded A (mean index score of 0.410; **Table 3.4**, Model 2). Vulnerability index score for minority status/language was 0.029-, 0.037-, and 0.040-unit greater (i.e., mean index score of 0.596, 0.604, and 0.607) in neighborhoods that were previously graded B, C, and D respectively, than those previously graded A (mean index score of 0.567; **Table 3.5**, Model 3). Additionally, vulnerability index score for housing type/transportation was 0.065-, 0.104-, and 0.121-unit greater (i.e., mean index score of 0.549, 0.588, and 0.605) in neighborhoods that were previously graded B, C, and D respectively, than those previously graded A (mean index score of 0.484; **Table 3.6**, Model 3).

3.3.2 Variation in the association between neighborhood HOLC grade and social vulnerability among cities

Except for household composition/disability SVI (**Table 3.4**), the relationship between neighborhood HOLC grade and SVI varied between cities (**Table 3.2–3.6**), suggesting a differential effects of historical redlining policies on present-day neighborhood SVI. The random effects ($\tau_{holc\ grades}$) of the relationship between HOLC grade and overall, socioeconomic, minority status/language, and housing type/transportation SVI were statistically significant ($p < 0.05$). Also, there was improvement in model fit (i.e., lower AIC and BIC values) for models that included HOLC grade as fixed and random effects (Model 3) compared to models that included HOLC grade only as fixed effects (Model 2).

Intra-city differences in overall and socioeconomic SVI between neighborhoods formerly graded D and A range from -0.03 in Camden, NJ for overall and socioeconomic SVI, respectively, to 0.74 for overall SVI and 0.76 for socioeconomic SVI in Greater Kansas City, MO (**Tables A1 and A2**). All cities that were analyzed that have data for both neighborhoods formerly graded A and D, except Camden, NJ, have greater present-day overall and socioeconomic SVI for neighborhood graded D relative to those graded A. For minority status/language SVI, the intra-city differences between neighborhoods formerly graded D and A range from -0.07 in Flint, MI to 0.57 in Greater Kansas City, MO, with 95% of cities included in our study that have data for both grade A and D neighborhoods showing greater present-day minority status/language SVI for neighborhood formerly graded D relative to those graded A (**Table A3**). For housing type/transportation SVI, the intra-city differences between neighborhoods formerly graded D and A range from -0.27 in Queens, NY to 0.59 in Oakland, CA, with 88% of cities included in our study that have data for both grade A and D neighborhoods showing greater present-day housing type/transportation SVI for neighborhood formerly graded D relative to those graded A (**Table A4**).

Table 3.2: Multilevel mixed effects models of overall SVI regressed on (1) no predictor, (2) fixed HOLC grades, and (3) fixed and random HOLC grades (n = 4171 HOLC neighborhoods, N = 71 cities or urban areas).

Variables	1. Unconditional model	2. Fixed HOLC grade model	3. Fixed + random HOLC grade model
HOLC grade			
A (Intercept)	0.556 (0.018)***	0.466 (0.021)***	0.471 (0.022)***
B		0.066 (0.013)***	0.064 (0.014)***
C		0.112 (0.013)***	0.105 (0.015)***
D		0.119 (0.016)***	0.113 (0.017)***
Variance components			
σ^2	0.068 (0.002)***	0.045 (0.001)***	0.045 (0.001)***
$\tau_{intercept}$	0.019 (0.004)***	0.020 (0.004)***	0.020 (0.004)***
$\tau_{holc\ grades}$			0.001 (0.0003)*
ICC	0.22		
Model fit			
AIC	821.3	-845.5	-851.7
BIC	828.1	-807.0	-811.0

Models 2 and 3 were adjusted for 1940 sociodemographic variables, including the proportion of non-White, employed residents, residents (age ≥ 25 years) with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home**.** Models' fit were compared using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). Lower AIC and BIC indicate better model fit. σ^2 is the variance components for within-city residual, $\tau_{intercept}$ is the variance components for between-city intercepts, and $\tau_{holc\ grade}$ is the variance components for between-city slopes. Values with asterisks are multilevel regression estimates with standard errors in parentheses. *p<0.05; **p<0.01, ***p<0.001.

Table 3.3: Multilevel mixed effects models of socioeconomic SVI regressed on (1) no predictor, (2) fixed HOLC grades, and (3) fixed and random HOLC grades (n = 4171 HOLC neighborhoods, N = 71 cities or urban areas).

Variables	1. Unconditional model	2. Fixed HOLC grade model	3. Fixed + random HOLC grade model
HOLC grade			
A (Intercept)	0.553 (0.022)***	0.457 (0.025)***	0.461 (0.025)***
B		0.070 (0.013)***	0.070 (0.014)***
C		0.119 (0.013)***	0.114 (0.015)***
D		0.125 (0.016)***	0.118 (0.017)***
Variance components			
σ^2	0.072 (0.002)***	0.045 (0.001)***	0.044 (0.001)***
$\tau_{intercept}$	0.029 (0.006)***	0.031 (0.006)***	0.031 (0.006)***
$\tau_{holc\ grades}$			0.001 (0.0003)*
ICC	0.29		
Model fit			
AIC	1057.9	-883.1	-887.6
BIC	1064.7	-844.7	-846.9

Models 2 and 3 were adjusted for 1940 sociodemographic variables, including the proportion of non-White, employed residents, residents (age ≥ 25 years) with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home**.** Models' fit were compared using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). Lower AIC and BIC indicate better model fit. σ^2 is the variance components for within-city residual, $\tau_{intercept}$ is the variance components for between-city intercepts, and $\tau_{holc\ grade}$ is the variance components for between-city slopes. Values with asterisks are multilevel regression estimates with standard errors in parentheses. *p<0.05; **p<0.01, ***p<0.001.

Table 3.4: Multilevel mixed effects models of household composition/disability SVI regressed on (1) no predictor, (2) fixed HOLC grades, and (3) fixed and random HOLC grades (n = 4171 HOLC neighborhoods, N = 71 cities or urban areas).

Variables	1. Unconditional model	2. Fixed HOLC grade model	3. Fixed + random HOLC grade model
HOLC grade			
A (Intercept)	0.443 (0.022)***	0.410 (0.025)***	0.410 (0.026)***
B		0.018 (0.014)	0.018 (0.014)
C		0.040 (0.014)**	0.041 (0.015)**
D		0.049 (0.017)**	0.049 (0.019)*
Variance components			
σ^2	0.065 (0.001)***	0.052 (0.001)***	0.051 (0.001)***
$\tau_{intercept}$	0.031 (0.006)***	0.032 (0.006)***	0.031 (0.006)***
$\tau_{holc\ grades}$			0.0005 (0.0004)
ICC	0.32		
Model filt			
AIC	667.9	-276.4	-277.0
BIC	674.7	-237.9	-236.2

Models 2 and 3 were adjusted for 1940 sociodemographic variables, including the proportion of non-White, employed residents, residents (age ≥ 25 years) with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home**.** Models' fit were compared using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). Lower AIC and BIC indicate better model fit. σ^2 is the variance components for within-city residual, $\tau_{intercept}$ is the variance components for between-city intercepts, and $\tau_{holc\ grade}$ is the variance components for between-city slopes. Values with asterisks are multilevel regression estimates with standard errors in parentheses. *p<0.05; **p<0.01, ***p<0.001.

Table 3.5: Multilevel mixed effects models of minority status/language SVI regressed on (1) no predictor, (2) fixed HOLC grades, and (3) fixed and random HOLC grades (n = 4171 HOLC neighborhoods, N = 71 cities or urban areas).

Variables	1. Unconditional model	2. Fixed HOLC grade model	3. Fixed + random HOLC grade model
HOLC grade			
A (Intercept)	0.598 (0.020)***	0.567 (0.021)***	0.567 (0.022)***
B		0.027 (0.010)**	0.029 (0.012)*
C		0.041 (0.010)***	0.037 (0.013)**
D		0.040 (0.012)**	0.040 (0.014)**
Variance components			
σ^2	0.035 (0.001)***	0.027 (0.001)***	0.026 (0.001)***
$\tau_{intercept}$	0.025 (0.004)***	0.025 (0.004)***	0.024 (0.004)***
$\tau_{holc\ grades}$			0.001 (0.0003)***
ICC	0.42		
Model fit			
AIC	-1932.7	-2979.2	-3006.7
BIC	-1926.0	-2940.8	-2966.0

Models 2 and 3 were adjusted for 1940 sociodemographic variables, including the proportion of non-White, employed residents, residents (age ≥ 25 years) with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home**.** Models' fit were compared using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). Lower AIC and BIC indicate better model fit. σ^2 is the variance components for within-city residual, $\tau_{intercept}$ is the variance components for between-city intercepts, and $\tau_{holc\ grade}$ is the variance components for between-city slopes. Values with asterisks are multilevel regression estimates with standard errors in parentheses. *p<0.05; **p<0.01, ***p<0.001.

Table 3.6: Multilevel mixed effects models of housing type/transportation SVI regressed on (1) no predictor, (2) fixed HOLC grades, and (3) fixed and random HOLC grades (n = 4171 HOLC neighborhoods, N = 71 cities or urban areas).

Variables	1. Unconditional model	2. Fixed HOLC grade model	3. Fixed + random HOLC grade model
HOLC grade			
A (Intercept)	0.569 (0.011)***	0.477 (0.015)***	0.484 (0.016)***
B		0.071 (0.012)***	0.065 (0.014)***
C		0.114 (0.012)***	0.104 (0.014)***
D		0.128 (0.015)***	0.121 (0.016)***
Variance components			
σ^2	0.049 (0.001)***	0.037 (0.001)***	0.037 (0.001)***
$\tau_{intercept}$	0.007 (0.001)***	0.007 (0.001)***	0.006 (0.001)***
$\tau_{holc\ grades}$			0.001 (0.0004)**
ICC	0.12		
Model fit			
AIC	-598.5	-1689.0	-1707.9
BIC	-591.7	-1650.6	-1667.1

Models 2 and 3 were adjusted for 1940 sociodemographic variables, including the proportion of non-White, employed residents, residents (age ≥ 25 years) with no high school diploma, homes needing major repairs, homes without a radio, homes without a mechanical refrigerator, homes without a central heating, homes with > 2 persons per room, multi-unit structures; number of persons per housing unit; and median value of home**.** Models' fit were compared using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). Lower AIC and BIC indicate better model fit. σ^2 is the variance components for within-city residual, $\tau_{intercept}$ is the variance components for between-city intercepts, and $\tau_{holc\ grade}$ is the variance components for between-city slopes. Values with asterisks are multilevel regression estimates with standard errors in parentheses. *p<0.05; **p<0.01, ***p<0.001.

3.4 Discussion

This study assessed the association between historical redlining, a discriminatory policy sanctioned by the U.S. government and an indicator of structural racism captured by HOLC security risk grade,[44] and present-day neighborhood social vulnerability in 71 U.S. urban areas. Our results show that neighborhoods that were redlined or graded "D: hazardous" by the HOLC in the 1930s have higher overall, socioeconomic, minority status and language, household composition and disability, and housing type and transportation SVI presently compared to those that were graded as "C: definitely declining", "B: still desirable", and "A: best". This indicates that historical redlining still negatively impacts neighborhoods with minority and low-income populations by preventing generations of their families from building wealth from home ownership.[45] Also, our findings indicate that neighborhoods that were historically redlined are presently more vulnerable or susceptible to the negative impacts of diseases, injuries, and natural or human-caused disaster.[28] Our results also show that the relationships between redlining and SVI varies between cities in the U.S.

The increased vulnerability of historically redlined neighborhoods to the effect of diseases and injuries has been highlighted in recent studies. Richardson et al. (2020) reported a significant association between redlining and the prevalence of risk factors that increase vulnerability to COVID-19 mortality in U.S. patients, including obesity, diabetes, hypertension, asthma, COPD, kidney disease, high cholesterol, and stroke.[28] Similarly, Nardone et al. (2020) found significant correlation between historical redlining and city-level prevalence of poor health outcomes in the U.S., including obesity, diabetes, sleep quality, asthma, cancer, CHD, high blood pressure, stroke, and mental health.[23] Other recent studies have reported higher prevalence of preterm birth, small-for-gestational age, perinatal mortality, poor cardiovascular health, poor physical health, poor mental, COVID-19 infection, firearm injuries, heat-related outcomes, and higher emergency department visits due to asthma.[21,22,24,26,27,41,44,46,47] This high vulnerability to diseases and injuries is due to the fact that historically redlined neighborhoods have a higher proportion of population, including minority and low-income residents, who lack the personal resources to cope with, resist, and recover from disease, injury, and disaster.[28] Our results show that social vulnerability due to high population of current residents who are ethnic minority, are of low socioeconomic status, and are vulnerable household members are greater in formerly redlined neighborhoods (*see* 2018 SVI, **Table 3.1**). This high social vulnerability is compounded by the poor conditions and lack of health-promoting resources in the neighborhood where they reside. For example, we found that historically redlined neighborhoods have a higher present-day social vulnerability related to poor housing conditions and transportation access (*see* 2018 SVI, **Table 3.1**). Crowded and poor housing conditions can increase susceptibility to infectious diseases, incidence of unintentional injuries, and incidence of heat-related illnesses; while lack of access to transportation can limit access to health promoting resources and opportunities, and reduce the speed of response to medical emergencies and disaster. Recent studies found that formerly redlined area have poorer contemporary health promoting resources and environments including poorer housing and built-environment characteristics that enhance heat vulnerability,[29] less greenspace,[1] less tree canopy cover,[2,35] greater impervious land cover area,[35] and warmer land surface temperature[35] than non-redlined areas in the U.S.[35]

We also found that the effect of historical redlining on present-day overall, socioeconomic, minority status/language, and housing type/transportation SVI varies between cities. While no studies have examined the differential effect of redlining on present-day SVI, our findings mirror other studies that reported differential effect of redlining on present-day neighborhood health outcomes, health behaviors, and environmental conditions in cities across the U.S. For instance, Nardone et al. (2020) found that the correlation between redlining and present-day health outcomes and unhealthy behaviors varied between US cities with redlining showing a strong, weak, or no association with different health outcomes and unhealthy behaviors.[23] Hoffman et al. (2020) also found a differential effect of redlining on present-day intra-urban heat among US cities with intra-city temperature differences between neighborhoods historically graded D and A ranging from +7.1° C in Portland, OR to -1.5° C in Joliet, IL.[35] These differences in the effect of redlining among cities are expected as local governments often have a huge influence over neighborhood development, housing, zoning and land use, and socioeconomic opportunities.[23] These findings suggest that interventions aimed at reducing the negative impact of structural discriminatory practices on present-day social vulnerability should be based on the current local context and target neighborhoods and populations that are still marginalized.

This study had some limitation. First, our study area was limited to cities and neighborhoods with HOLC map that overlapped with 1940 U.S. census tract boundaries. This nonrandom selection of cities and neighborhoods may affect the generalization of our findings to other places with HOLC maps that did not overlap with 1940 census tracts.[1] Second, because of limited data availability for the 1930 census, we adjusted for 1940 census sociodemographic characteristics, whereas the 1930 census sociodemographic is a better representation of the neighborhood characteristics before the creation of HOLC security map.[29] This way we assume similarities in the neighborhood sociodemographic composition between the two different census periods.[29].

Addressing the structural factors associated with higher neighborhood social vulnerability is important for increasing health equity and environmental justice. In this study, we found that historical redlining was associated with greater present-day social vulnerability indicating the persistent impact of historical structural racism on current neighborhood vulnerability. Considering the higher vulnerability of formerly redlined neighborhood, local government should invest in and provide health-promoting resources in these economically disinvested neighborhoods to reduce their susceptibility to the negative impact of diseases and disasters. Future studies should examine the mediating effect of neighborhood SVI on the relationship between historical redlining and present-day health outcomes and health behaviors. Also, future research should examine how redlining affect the change in neighborhood social vulnerability over time in order to predict and prevent increase in neighborhood social vulnerability in the future.

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Chapter 4: Historical redlining and current racial disparities in sports and recreational injury hospitalizations in the United States

Abstract

Background: In this study, we examined the association between historical redlining, a government-sanctioned racial discriminatory practice of the 1930s, and present-day sports and recreational injury (SRI) hospitalization in the U.S.

Methods: We obtained 2011 SRI hospitalization data in the U.S. from the National Inpatient Sample database, linked it to 1930s Home Owners' Loan Corporation (HOLC) redlining maps, and assigned U.S. hospitals to one of three HOLC grades (A+B – best/still desirable, C – definitely declining, and D – hazardous/redlined). Generalized linear mixed models, accounting for sample weight, stratified sampling, and patient clustering within hospitals, were used to examine these relationships.

Results: We found no association between HOLC grade and the odds of hospitalization for SRI among all racial/ethnic groups after adjusting for confounders; however, HOLC grade was associated with length of stay (**LOS**) in Black and Hispanic patients, and total hospital charges per discharge among Hispanic patients. LOS was 54% longer for Black patients and 13% longer for Hispanic patients hospitalized in historically redlined neighborhoods (HOLC grade D) compared to those hospitalized in neighborhoods historically graded as "A+B". Total charges were 27% higher for Hispanic patients hospitalized in neighborhoods historically graded as "C" compared to those hospitalized in neighborhoods historically graded as "A+B". We also found that the associations between HOLC grade and LOS for Black and White patients, and between

HOLC grade and total charges for Hispanic and White patients were modified by present-day neighborhood social vulnerability.

Conclusion: This study indicates that redlining, an indicator of structural racism, has a lasting impact on health outcomes.

Keywords: Historical redlining, social vulnerability, racial disparities, sports and recreational injury, hospitalizations, structural racism.

4.1 Background

Approximately 9 million people are injured annually from sports and recreation, more than a third seek treatment in the emergency department (**ED**), and several thousands are hospitalized for more severe injuries in the U.S.[1,2] While only a relatively small number of sports and recreational injuries (**SRI**) result in hospitalization, compared to those treated in EDs or outpatient clinics, these injuries are often more severe.[2] Due to their severity, they can have detrimental effects on the physical, mental, and emotional health of people, and place a heavy burden on the health care system and society as a whole; this highlights the importance of ensuring safety during sports and recreational activities and preventing SRI. Efforts to increase safety and prevent SRI may include improving neighborhood environments or social vulnerabilities (i.e., socioeconomic and demographic factors that make some communities more susceptible or less resilient to the adverse impact of injury, disease outbreak, and natural or human-caused disaster[3–5]) since there is a robust body of evidence that link neighborhood environment to SRI.[6] Recent studies have shown that neighborhood environments are associated with SRI;[6] however, none of these studies examined the historical context that shapes these environments, thereby failing to recognize the impact of structural racist policies and practices, such as historical redlining, on SRI among those identifying as a racial or ethnic minority.

Historical redlining are discriminatory practices of the 1930s that denied access to loans in neighborhoods with high racial/ethnic minority and low-income populations.[7,8] Redlining was institutionalized through security maps created by the federal Home Owners' Loan Corporation (**HOLC**) in the 1930s to assess mortgage lending risk in U.S. cities.[9] HOLC graded neighborhoods that were mostly White US-born residents "A: best" (colored green) or "B: still desirable" (colored blue), deeming these neighborhoods favorable for investment, while neighborhoods with significant racial/ethnic minorities and foreign-born residents were often graded as “C: definitely declining” (colored yellow) or “D: hazardous” (colored red or redlined), deeming these neighborhood very risky for investment.[7,8] Neighborhoods that were deemed risky for investment experienced disinvestments for decades resulting in high present-day social vulnerability or deprivation in these historically marginalized neighborhoods.[9] Recent studies have reported association between historical redlining and poor health outcomes including lower life expectancy at birth, increased exposure to COVID-19, high prevalence of obesity, diabetes, hypertension, high blood pressure, heart disease, asthma, preterm birth, and high firearm injury rates;[10–16] however, no study to date has examined the effect of redlining on SRI or SRI hospitalizations.

Therefore, the aim of this study was to examine the racial and ethnic disparities in the association between historical redlining and present-day SRI hospitalization, length of stay, and total hospital charges, considering that redlining was both a policy and practice that specifically discriminated against racial and ethnic minorities. We also examined whether the associations between historical redlining and present-day SRI hospitalization, length of stay, and total hospital charges were modified by present-day neighborhood characteristics (i.e., social vulnerability, **SVI**) for different racial and ethnic groups because of the historic nature of redlining and the fact that public health intervention can improve contemporary neighborhood social vulnerability.[9]

4.2 Methods

4.2.1 Data collection and linkage

This study was a retrospective analysis of hospitalization due to SRI in neighborhoods formerly graded by the HOLC across the U.S. We obtained the 2011 SRI hospitalization data in the U.S. from the Healthcare Cost and Utilization Project (**HCUP**) National Inpatient Sample (**NIS**) database.[17] Although more recent NIS data are available (NIS 2012-2020 datasets), we used the 2011 NIS SRI hospitalization data because hospital addresses, which allowed us to link NIS data with other datasets that included key geographical information, were unavailable in NIS datasets after 2011. The NIS is the largest publicly available source of all-payer inpatient care data in the U.S.[18] Unweighted, the 2011 NIS contains data from 8,023,590 hospitalizations from 1,049 hospitals located in 46 states. The number of hospitals sampled was designed to approximate a 20% stratified sample of community hospitals in the U.S., making this data a nationally representative sample of patients.[18] The 2011 NIS uses a stratified probability sample of community hospitals with the probabilities of sampling proportional to the number of U.S. community hospitals in each stratum.[18] The community hospitals were divided into strata based on five characteristics of hospitals including teaching status, bed size, ownership/control, urban/rural location, and U.S. region.[18] Discharge-level and hospital-level weights were provided to produce national estimates.

Also, we obtained nationwide data of the 1930's HOLC residential security risk (redlining) maps that were digitized by a team at the University of Richmond, University of Maryland, John Hopkins, and Virginia Tech.[19] The maps are part of the "Mapping Inequality: Redlining in New Deal America" project which involves georectification and digitization of HOLC maps of cities across the U.S.[20] The digitized maps consist of 8,878 HOLC defined neighborhood boundaries (or polygons) of 196 cities and 38 states as of June 11, 2021. The HOLC neighborhood maps were used to assign U.S. community hospitals to one of three HOLC grades (A+B – best/still desirable, C – definitely declining, and D – hazardous). HOLC grades A and B were combined to form grade A+B in this study because of the limited SRI data for grade A neighborhoods (i.e., 0.8% of patients were hospitalized in HOLC grade A neighborhoods). The HOLC maps were used to assess the effects of redlining on SRI hospitalization, length of hospital stay and total hospital charges for SRI.

Additionally, we obtained the 2010 SVI census tract data from the Centers for Disease Prevention and Control and Agency for Toxic Substances and Disease Registry (CDC/ATSDR) website.[21] SVI makes it possible to rank neighborhoods by socioeconomic disadvantage across the U.S., and these data were used to assign U.S. community hospitals to one of two neighborhood SVI categories (low SVI and high SVI). The SVI data were used to assess the interaction effects of SVI and HOLC grade on SRI hospitalization, length of hospital stay and total hospital charges for SRI.

Geographic information system (**GIS**) was used to geocode the addresses of the community hospitals. The geocoded hospital data were then linked to the 1930s HOLC neighborhood data, and the 2010 SVI neighborhood data.

All patients who were diagnosed of SRI in the NIS database and who were hospitalized in formerly redlined neighborhoods in 2011 were selected for analysis. The *International Classification of Diseases, 9th Revision, Clinical Modification (**ICD-9-CM**)*, external-cause-of injury codes (**E-codes**) that were used to identify and select patients hospitalized for SRI are listed in **Table 4.3**.

4.2.2 Statistical analysis

Weighted descriptive statistics were used to characterize sports and recreational injury hospitalizations in 2011 with respect to individual confounders, including age, sex, payer information, median household income of patient's ZIP Code, alcohol-use disorder, substance-use disorder, obesity comorbidity status, admission month/season, admission day, teaching status of hospital, bed size of hospital, patient's disposition, sports and recreational activity type, injured body region, injury type, and injury severity, by race/ethnicity. These categorical variables were described using frequencies and percentages. Length of hospitalization and total hospital charges per discharge were described using means, standard deviations (**SD**), medians, and ranges (minimum, maximum). Chi-square tests and one-way analysis of variance (**ANOVA**) models were used for comparison of categorical and continuous variables, respectively, across race/ethnicity groups. For the ANOVA, length of hospitalization and total hospital charges were log-transformed to meet the statistical assumption of normality. Tukey-Kramer test was used to conduct post-hoc pairwise mean comparisons with adjustment made for multiplicity.

Generalized linear mixed models (**GLMMs**) were used to examine race/ethnicity-stratified associations between historical redlining HOLC grades and SRI hospitalization, length of hospital stay, and total hospital charges per discharge in the U.S. The decision to stratify the model results by race/ethnicity was supported by statistically significant interactions between race/ethnicity and HOLC grade ($p < 0.0001$) in separately generated models that included interaction term, and to ease interpretation of results. SRI hospitalization was a binary outcome and therefore was modeled using a GLMM specifying a binomial distribution. Length of stay and total charges per discharge were over-dispersed count outcome variables and thus were modeled using GLMMs specifying negative binomial distributions. All models were two-level

GLMMs with a random intercept to account for the nesting or clustering of patients within hospitals or hospital neighborhoods and the variance component covariance structure for random effects was applied. Sample weights and stratified sampling were also accounted for in the GLMMs. To assess how present-day neighborhood characteristics (i.e., social vulnerability) modify the race/ethnicity-stratified association between redlining and all study outcomes, additional GLMM models were created that included an interaction term between SVI and HOLC grade. A Bonferroni adjustment was used to account for multiplicity due to three study outcomes. Statistical significance was taken at the $\alpha = 0.05$ level. All analyses were conducted using SAS Version 9.4 (SAS Institute Inc., Cary, NC) and ArcGIS Pro.

4.3 Results

4.3.1 Characteristics of sports and recreational injury hospitalizations in formerly redlined area

Table 4.1 contains patient, hospital, and neighborhood characteristics of SRI hospitalizations by race/ethnicity in areas formerly graded by the Home Owner’s Loan Corporation (HOLC) in the 1930s in the U.S. A total of 3,769 SRI hospitalizations were identified in the NIS data sample, representing an estimated weighted total of 18,297 SRI hospitalizations in areas formerly graded by the HOLC in the U.S. Of all patients hospitalized for SRI, more than a third (38.0%) were younger than age 25, more than two-thirds (68.9%) involved male patients, and about two-thirds (66.4%) were White patients. A greater proportion of Black and Hispanic patients hospitalized for SRI, compared to White patients, were younger than 25 (48.0% Black; 49.0% Hispanic; 32.7% White), were male (79.1% Black; 78.2% Hispanic; 64.7% White), were uninsured (13.2% Black; 15.5% Hispanic; 7.2% White), cited

Medicaid as source of payment (40.2% Black; 34.2% Hispanic; 11.0% White), lived in ZIP Code with worse median household income (51.9% Black; 29.3% Hispanic; 15.0% White), and had alcohol-use disorder (9.5% Black; 9.3% Hispanic; 5.7% White) and substance-use disorder (8.6% Black; 4.4% Hispanic; 3.2% White).

About a third of SRI hospitalizations occurred in the summer (32.8%) and on weekends (32.9%), and about one-half (53.0%) of patients were hospitalized in the Northeast region. More than two-thirds (68.2%) of SRI hospitalizations were attributed to fractures and majority of the injury (80.9%) resulted in minor to moderate loss of function. The most common body regions of SRI hospitalizations were lower extremities (35.2%) followed by head/neck (25.5%). SRI hospitalizations were greater in teaching hospitals (93.4%) and hospitals with high bed volume (68.9%). The main source of SRI hospitalization was routine admission for Black (64.7%) and White (48.5%) patients, while emergency department was the main source of admission for Hispanic (64.7%) patients. Most patients hospitalized for SRI were discharged routinely (77.2% Black; 78.8% Hispanic; 71.1% White). The proportion of patients transferred to short-term hospitals, nursing facilities or home health care was greater for White patients (27.0%) compared to Black (19.1%) and Hispanic (19.8%) patients. Indoor/outdoor recreations or activities accounted for a greater proportion of SRI hospitalizations (57.2% Black; 64.6% Hispanic; 74.6% White). The proportion of SRI hospitalizations due to team/individual sports or athletics was greater for Black (27.2%) patients compared to White (13.9%) and Hispanic (16.2%) patients.

A higher proportion of Black (72.1%) patients were hospitalized in neighborhoods with high social vulnerability (SVI), compared to Hispanic (65.8%) and White (63.4%) patients. Also, a higher proportion of Black (40.1%) patients were hospitalized in historically redlined neighborhoods (HOLC grade D), compared to Hispanic (29.0%) and White (32.6%) patients (**Table 4.1**).

Table 4.1 also contains the mean and median scores for hospital length of stay and total charges per discharge. The average length of stay in hospital for SRI was 3.9 days (median = 1.9 days) and the average hospital charges per discharge was $43,467 (median = $25,972). Average hospital charges per discharge were significantly lower for Black ($34,136) patients compared to Hispanic ($44,708) and White ($45,433) patients (**Table 4.1**).

4.3.2 Association between historical redlining and SRI hospitalization, length of stay, and total charges.

Table 4.2 summarizes the race-stratified association between HOLC grade and SRI hospitalizations, length of stay, and total charges adjusted for confounders. There was no statistically significant association between HOLC grade and SRI hospitalizations for Black ($p > 0.9999$), Hispanic ($p = 0.9213$), and White patients ($p > 0.9999$). However, significant associations were observed between HOLC grade and length of stay for Black ($p = 0.0006$) and Hispanic ($p = 0.0102$), but not for White patients ($p = 0.0651$).

Black patients who were hospitalized in historically redlined neighborhoods (HOLC grade D or "hazardous") had 53.66% ($\beta = 53.66$, 95% CI: 18.15, 99.85) longer length of stay compared to Black patients hospitalized in HOLC grade A+B ("best/still desirable") neighborhoods. Black patients hospitalized in neighborhoods historically graded as C ("definitely declining") also had longer length of stay ($\beta = 41.61$, 95% CI: 12.61, 78.07) compared to those hospitalized in HOLC grade A+B ("best/still desirable) neighborhoods. Similarly, Hispanic patients hospitalized in neighborhoods historically graded as C had 40.61% ($\beta = 40.61$, 95% CI: 9.38, 80.74) longer length of stay compared to Hispanic patients hospitalized in HOLC grade A+B neighborhoods, while those hospitalized in historically redlined neighborhoods (HOLC grade D) had 13.05% (β = 13.05, 95% CI: -16.50, 53.05) longer length of stay compared to those hospitalized in HOLC grade A+B neighborhoods; however, the difference was not statistically significant.

We also found a significant association between HOLC grade and total hospital charges for Hispanic patients (p = 0.0060). The patterns observed for total hospital charges were similar to those observed for length of stay for Hispanic patients. Hispanic patients who were hospitalized in neighborhoods historically graded C had 26.54% (β = 26.54, 95% CI: 0.47, 59.38) higher total charges per discharge compared to those hospitalized in HOLC grade A+B neighborhoods, while no difference in total charges was observed between those hospitalized in historically redlined neighborhoods (HOLC grade D) and those hospitalized in HOLC grade A+B neighborhoods (β = -9.85, 95% CI: -31.55, 18.73). There were no associations between HOLC grade and total charges for Black (p = 0.1386) and White patients (p > 0.9999).

Figure 4.1 shows the results for models that examines whether significant associations between HOLC grade and length of stay or total hospital charges for each race/ethnicity were modified by contemporary neighborhood social vulnerability. The associations between HOLC grade and length of stay were modified by contemporary neighborhood social vulnerability (SVI) in Black (**Figure 4.1A**; p = 0.0450) and White patients (**Figure 4.1C**; p = 0.0006), but not among Hispanic patients (**Figure 4.1B**; p = 0.0624). For example, White patients who were hospitalized in high-vulnerable historically redlined neighborhoods (HOLC grade D) had 24.87% (β = -24.87, 95% CI: -37.32, -9.96) shorter length of stay compared to those hospitalized in high-vulnerable historical grade A+B neighborhoods; however, there was no statistically significant difference in length of stay for White patients who were hospitalized in low-vulnerable historically redlined neighborhoods (HOLC grade D) compared to those hospitalized in low-vulnerable historical grade A+B neighborhoods (β = 30.89, 95% CI: -0.71, 72.55). Similarly, there were also no statistically significant differences in length of stay for White patients who were hospitalized in high-vulnerable (β = -11.58, 95% CI: -26.31, 6.10) and low-vulnerable (β = -6.18, 95% CI: -19.76, 9.70) historical grade C neighborhoods compared to those hospitalized in high-vulnerable and low-vulnerable historical grade A+B neighborhoods, respectively. Black patients who were hospitalized in low-vulnerable historical grade C neighborhoods had 67.01% (β = 67.01, 95% CI: 26.42, 120.25) longer length of stay compared to those hospitalized in low-vulnerable historical grade A+B neighborhoods; however, there was no statistically significant difference in length of stay for Black patients who were hospitalized in high-vulnerable historical grade C neighborhoods compared to those hospitalized in high-vulnerable historical grade A+B neighborhoods (β = 17.56, 95% CI: -21.87, 76.88). Similarly, there were also no statistically significant difference in length of stay for Black patients who were hospitalized in low-vulnerable (β = 9.99, 95% CI: -29.40, 71.36) and high-vulnerable (β = 40.69, 95% CI: -5.82, 110.16) historically redlined neighborhoods (HOLC grade D) versus those hospitalized in low-vulnerable and high-vulnerable historical grade A+B neighborhoods, respectively; however, the strength of association between historical redlining HOLC grade D and length of hospital stay appeared slightly stronger in Black patients hospitalized in high-vulnerable areas than in Black patients hospitalized in low-vulnerable areas.

We also found that the associations between HOLC grade and total hospital charges were modified by contemporary neighborhood SVI among Hispanic and White patients (**Figure 4.1E and 4.1F**; p = 0.0003) but not among Black patients (**Figure 4.1D**; p = 0.0510), with the relationships observed in low-vulnerable areas versus high-vulnerable areas for Hispanic and

White patients pointing toward opposite directions. For example, in high-vulnerable historic grade C neighborhoods, Hispanic and White patients who were hospitalized had 99.93% (β = 99.93, 95% CI: 44.77, 176.10) and 45.27% (β = 45.27, 95% CI: 4.91, 101.15) higher total charges compared to Hispanic and White patients hospitalized in high-vulnerable HOLC grade A+B neighborhoods. In contrast, Hispanic and White patients who were hospitalized in low-vulnerable historic grade C neighborhoods had 23.26% (β = -23.26, 95% CI: -44.29, 5.69) and 32.77% (β = -32.77, 95% CI: -48.23, -12.70) lower total charges compared to those patients hospitalized in low-vulnerable HOLC grade A+B neighborhoods; however, the difference for Hispanic patients was not statistically significant. Similarly, Hispanic and White patients who were hospitalized in low-vulnerable historically redlined neighborhoods (HOLC grade D) had 41.59% (β = -41.59, 95% CI: -63.59, -6.29) and 47.48% (β = -47.48, 95% CI: -68.81, -11.56) lower total charges, respectively, compared to Hispanic and White patients hospitalized in low-vulnerable HOLC grade A+B neighborhoods, even though they experienced slightly, but not statistically significant, longer length of stay (*see* **Figure 4.1B & 4.IC**). In contrast, Hispanic and White patients who were hospitalized in high-vulnerable historically redlined neighborhoods had 27.53% (β = 27.53, 95% CI: -7.27, 75.38) and 33.35% (β = 33.35, 95% CI: -2.17, 81.76) higher total charges, respectively, compared to Hispanic and White patients hospitalized in high-vulnerable HOLC grade A+B neighborhoods; however, the differences were not statistically significant.

Table 4.1: Patient and hospital characteristics of sports and recreational injury hospitalization in formerly redlined areas.

Characteristics	**Total (n = 18,297)**	**Black (n = 2,714)**	**Hispanic (n = 2,057)**	**White (n = 12,153)**	**Other (n = 1,372)**	**P-value**
Age, n (%)						<0.0001
< 25	6956 (38.0)	1303 (48.0)	1008 (49.0)	3978 (32.7)	668 (48.7)	
25 - 49	5316 (29.1)	869 (32.0)	703 (34.2)	3358 (27.6)	386 (28.1)	
50 - 74	4321 (23.6)	457 (16.8)	247 (12.0)	3383 (27.8)	234 (17.0)	
≥ 75	1704 (9.3)	86 (3.2)	99 (4.8)	1434 (11.8)	84 (6.1)	
Sex, n (%)						<0.0001
Female	5694 (31.1)	568 (20.9)	449 (21.8)	4287 (35.3)	390 (28.4)	
Male	12603 (68.9)	2147 (79.1)	1608 (78.2)	7866 (64.7)	982 (71.6)	
Payer information, n (%)						<0.0001
Medicaid	3498 (19.1)	1090 (40.2)	704 (34.2)	1341 (11.0)	363 (26.4)	
Medicare	3058 (16.7)	259 (9.5)	170 (8.3)	2496 (20.5)	134 (9.7)	
Private insurance	9195 (50.3)	877 (32.3)	691 (33.6)	6989 (57.5)	637 (46.4)	
Uninsured	1734 (9.5)	362 (13.2)	319 (15.5)	873 (7.2)	181 (13.2)	
No charge/Other	811 (4.4)	126 (4.7)	173 (8.4)	454 (3.7)	58 (4.2)	
Median household income for patient's ZIP Code, n (%)						<0.0001
1st Quartile ($1 - $38,999)	4068 (22.9)	1323 (51.9)	577 (29.3)	1787 (15.0)	381 (29.0)	
2nd Quartile ($39,000 - $47,999)	3815 (21.5)	408 (16.0)	665 (33.8)	2459 (20.7)	283 (21.5)	
3rd Quartile ($48,000 - $63,999)	4351 (24.5)	424 (16.6)	479 (24.3)	3118 (26.2)	330 (25.2)	
4th Quartile (≥ $64,000)	5494 (31.0)	395 (15.5)	249 (12.6)	4533 (38.1)	318 (24.2)	
Alcohol-use disorder, n (%)						0.0071
No	17084 (93.4)	2457 (90.5)	1866 (90.7)	11457 (94.3)	1306 (95.1)	
Yes	1213 (6.6)	258 (9.5)	191 (9.3)	697 (5.7)	67 (4.9)	
Substance-use disorder, n (%)						<0.0001
No	17542 (95.9)	2480 (91.4)	1966 (95.6)	11767 (96.8)	1329 (96.8)	
Yes	755 (4.1)	235 (8.6)	91 (4.4)	386 (3.2)	43 (3.2)	
Obesity, n (%)						0.9392
No	17624 (96.3)	2613 (96.2)	1974 (96.0)	11709 (96.3)	1328 (96.8)	
Yes	673 (3.7)	102 (3.8)	83 (4.0)	444 (3.7)	44 (3.2)	
Admission month/season, n (%)						0.6589
Sept. - Nov. (Fall)	4514 (25.2)	702 (26.3)	531 (26.1)	2950 (24.9)	330 (24.3)	
March - May (Spring)	4384 (24.5)	695 (26.0)	517 (25.4)	2813 (23.7)	359 (26.5)	
June - Aug. (Summer)	5870 (32.8)	840 (31.4)	703 (34.5)	3876 (32.7)	451 (33.2)	
Dec. - Feb. (Winter)	3148 (17.6)	437 (16.3)	286 (14.0)	2209 (18.6)	217 (16.0)	
Admission day, n (%)						0.0794

Characteristics	Total (n = 18,297)	Black (n = 2,714)	Hispanic (n = 2,057)	White (n = 12,153)	Other (n = 1,372)	P-value
Mon. - Fri. (Weekday)	12270 (67.1)	1812 (66.8)	1416 (68.9)	8035 (66.1)	1006 (73.3)	
Sat. - Sun. (Weekend)	6027 (32.9)	902 (33.2)	641 (31.1)	4118 (33.9)	366 (26.7)	
Teaching status of hospital, n (%)						0.5369
Nonteaching	1199 (6.6)	159 (5.8)	210 (10.2)	750 (6.2)	80 (5.9)	
Teaching	17098 (93.4)	2556 (94.2)	1847 (89.8)	11403 (93.8)	1292 (94.1)	
Bed size of hospital, n (%)						0.8186
Large	12607 (68.9)	1627 (59.9)	1446 (70.3)	8480 (69.8)	1055 (76.8)	
Medium	4628 (25.3)	915 (33.7)	470 (22.9)	2982 (24.5)	261 (19.0)	
Small	1062 (5.8)	173 (6.4)	141 (6.8)	692 (5.7)	57 (4.2)	
Disposition of patients, n (%)						0.0003
Routine discharge	13427 (73.4)	2088 (77.2)	1620 (78.8)	8645 (71.1)	1074 (78.2)	
Transfer/Discharge to short-term hospital/nursing facility/home health care	4469 (24.4)	515 (19.1)	406 (19.8)	3279 (27.0)	268 (19.5)	
Died	166 (0.9)	29 (1.1)	**	116 (1.0)	16 (1.2)	
Other	225 (1.2)	72 (2.6)	26 (1.2)	113 (0.9)	15 (1.1)	
Admission source, n (%)						<0.0001
Emergency department	2260 (32.4)	212 (19.2)	519 (64.2)	1376 (29.3)	152 (41.7)	
Routine/other	3355 (48.0)	717 (64.7)	222 (27.5)	2280 (48.5)	136 (37.3)	
Transfer	1369 (19.6)	178 (16.1)	67 (8.3)	1046 (22.3)	76 (21.0)	
Injured body region, n (%)						<0.0001
Head/neck	3982 (25.5)	544 (24.7)	505 (28.9)	2659 (25.5)	274 (23.0)	
Lower extremity	5489 (35.2)	913 (41.4)	705 (40.5)	3460 (33.1)	410 (34.5)	
Spinal cord injury	249 (1.6)	54 (2.5)	33 (1.9)	152 (1.5)	10 (0.8)	
Torso	2156 (13.8)	228 (10.3)	150 (8.6)	1671 (16.0)	108 (9.1)	
Upper extremity	2776 (17.8)	367 (16.6)	306 (17.6)	1781 (17.1)	321 (27.0)	
Vertebral column injury	853 (5.5)	75 (3.4)	45 (2.6)	672 (6.4)	62 (5.2)	
Other/Unspecified	81 (0.5)	26 (1.2)	**	51 (0.5)	**	
Injury type, n (%)						<0.0001
Dislocation	252 (1.6)	83 (3.8)	42 (2.4)	123 (1.2)	**	
Fracture	10636 (68.2)	1369 (62.0)	1192 (68.4)	7239 (69.3)	837 (70.3)	
Internal organ	2917 (18.7)	379 (17.2)	297 (17.0)	2051 (19.6)	189 (15.9)	
Open wound	508 (3.3)	107 (4.9)	39 (2.2)	306 (2.9)	56 (4.7)	
Strains/Sprains	391 (2.5)	157 (7.1)	26 (1.5)	155 (1.5)	52 (4.4)	
Contusion/Superficial wound	364 (2.3)	42 (1.9)	84 (4.8)	200 (1.9)	38 (3.2)	
Other/Unspecified	516 (3.3)	69 (3.1)	64 (3.7)	371 (3.6)	12 (1.0)	
Injury severity, n (%)						<0.0001

Characteristics	Total (n = 18,297)	Black (n = 2,714)	Hispanic (n = 2,057)	White (n = 12,153)	Other (n = 1,372)	P-value
Minor loss of function	7448 (40.7)	1315 (48.4)	1025 (49.8)	4472 (36.8)	636 (46.3)	
Moderate loss of function	7358 (40.2)	1003 (36.9)	713 (34.7)	5156 (42.4)	486 (35.4)	
Major loss of function	2761 (15.1)	287 (10.6)	249 (12.1)	2049 (16.9)	177 (12.9)	
Extreme loss of function	730 (4.0)	110 (4.1)	70 (3.4)	475 (3.9)	74 (5.4)	
Sports and recreational activity, n (%)						<0.0001
Indoor/Outdoor recreation/activity	12648 (69.8)	1551 (57.2)	1328 (64.6)	8942 (74.6)	826 (60.4)	
Individual/Team sports	2925 (16.1)	736 (27.2)	333 (16.2)	1668 (13.9)	188 (13.7)	
Other/Unspecified	2551 (14.1)	423 (15.6)	395 (19.2)	1379 (11.5)	354 (25.9)	
Hospital census region						<0.0001
Midwest	1787 (9.8)	112 (4.1)	191 (9.3)	1285 (10.6)	199 (14.5)	
Northeast	9692 (53.0)	1492 (55.0)	989 (48.1)	6424 (52.9)	787 (57.3)	
South	4098 (22.4)	917 (33.8)	148 (7.2)	2889 (23.8)	144 (10.5)	
West	2720 (14.9)	193 (7.1)	730 (35.5)	1554 (12.8)	243 (17.7)	
Neighborhood overall social vulnerability (SVI)						0.1075
Low SVI (<50th percentile)	6665 (36.4)	759 (27.9)	704 (34.2)	4443 (36.6)	759 (55.3)	
High SVI (≥50th percentile)	11632 (63.6)	1956 (72.1)	1353 (65.8)	7710 (63.4)	614 (44.7)	
HOLC grade						0.9572
A – best	150 (0.8)	27 (1.0)	**	119 (1.0)	**	
B – still desirable	3622 (19.8)	458 (16.9)	421 (20.5)	2477 (20.4)	265 (19.3)	
C – definitely declining	8276 (45.2)	1140 (42.0)	1034 (50.3)	5594 (46.0)	508 (37.0)	
D – hazardous (redlined)	6250 (34.2)	1090 (40.1)	597 (29.0)	3964 (32.6)	599 (43.7)	
Length of hospitalization (days)						<0.0001
mean±SEM	3.91 (0.17)	3.70 (0.43) [a]	3.86 (0.30) [a]	3.98 (0.17) [a]	3.83 (0.37) [a]	
median (q1, q3)	1.92 (0.79, 3.92)	1.77 (0.63, 3.76)	1.86 (0.84, 3.87)	2.02 (0.84, 3.99)	1.65 (0.73, 3.55)	
min, max	0, 216	0, 56	0, 51	0, 216	0, 79	
Total charges per discharge (USD)						
mean±SEM	43467 (5216.34)	34136 (5100.3) [a]	44708 (4813.0) [a]	45433 (6209.7) [a]	42819 (6009.0) [a]	<0.0001
median (q1, q3)	25972 (13811, 49317)	20895 (9510, 40687)	29687 (16259, 51658)	27818 (14732, 51809)	23085 (13389, 42020)	
min, max	735, 1509374	948, 402535	2052, 706956	735, 1509374	2812, 1136932	

P-values are based on chi-square tests and one-way analysis of variance (ANOVA) for categorical and continuous variables, respectively. Tukey's test was used for pairwise mean comparison of the different race/ethnicity for length of stay and total charges with adjustment made for multiple comparisons. Means with same letters are not significantly different from each other. Numbers below 10 are masked with **.

Table 4.2: Adjusted association between neighborhood HOLC grade and SRI outcomes stratified by race.

			SRI Hospitalization			
Variables	Black (n = 6636; nSRI = 411)		Hispanic (n = 3775; nSRI = 320)		White (n = 27198; nSRI = 2004)	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
HOLC grade		*>0.9999*		*0.9213*		*>0.9999*
A+B	Reference		Reference		Reference	
C	1.62 (0.48, 5.48)	1.0000	1.48 (0.43, 5.07)	1.0000	1.13 (0.49, 2.59)	1.0000
D	1.16 (0.27, 5.04)	1.0000	0.73 (0.19, 2.83)	1.0000	0.86 (0.31, 2.39)	1.0000
			Length of Stay			
Variables	Black (n = 411)		Hispanic (n = 320)		White (n = 2004)	
	% Change (95% CI)	p-value	% Change (95% CI)	p-value	% Change (95% CI)	p-value
HOLC grade		*0.0006*		*0.0102*		*0.0651*
A+B	Reference		Reference		Reference	
C	41.61 (12.61, 78.07)	0.0008	40.61 (9.38, 80.74)	0.0035	-4.90 (-15.29, 6.77)	0.8971
D	53.66 (18.15, 99.85)	0.0003	13.05 (-16.50, 53.05)	0.9971	-14.67 (-26.14, -1.42)	0.0255
			Total Hospital Charges			
Variables	Black (n = 407)		Hispanic (n = 300)		White (n = 1980)	
	% Change (95% CI)	p-value	% Change (95% CI)	p-value	% Change (95% CI)	p-value
HOLC grade		*0.1386*		*0.0060*		*>0.9999*
A+B	Reference		Reference		Reference	
C	-16.30 (-32.62, 3.98)	0.1488	26.54 (0.47, 59.38)	0.0437	-5.50 (-22.21, 14.81)	1.0000
D	-22.51 (-39.66, -0.48)	0.0441	-9.85 (-31.55, 18.73)	1.0000	-3.46 (-24.35, 23.20)	1.0000

OR: Odds Ratio – represents a binary outcome for the odds of being hospitalized for SRI versus the odds of not being hospitalized for SRI.
% change (95% CI) was calculated using [(exp(β) -1)*100] where β is the regression coefficient of HOLC grades for length of stay and total charges with negative binomial distribution (log link). CI: Confidence Interval; Italicized p-values are the values of the Type III F-tests of fixed HOLC grade effects. P-value ≤ 0.05 indicates statistically significant effects. Models are adjusted for age, sex, payer information, median household income of patient's ZIP Code, alcohol-use disorder, substance-use disorder, obesity comorbidity status, admission month/season, admission day, injured body region, injury type, injury severity, number of registered nurses per 1000 adjusted inpatient days, teaching status of hospital, bed size of hospital, hospital's census region, and neighborhood social vulnerability. Model for total hospital charges was also adjusted for length of stay. n – is the unweighted total number of patients used for analysis; nSRI – is the unweighted number of patients with SRI.

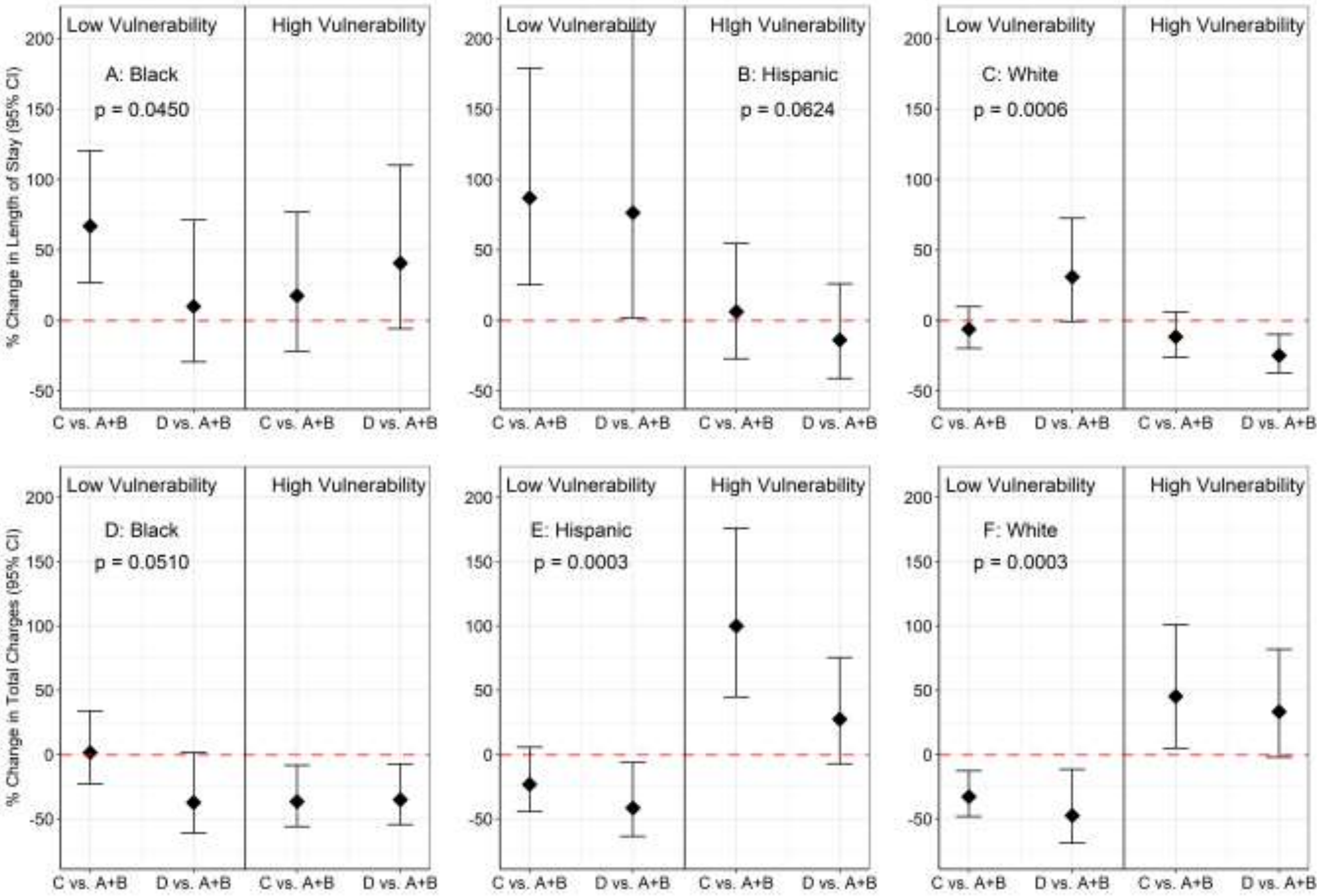

Figure 4.1: Modifying effect of neighborhood vulnerability on the association between HOLC grade and SRI outcomes. The figure shows the percent change in length of stay and total charges per discharge for comparisons between HOLC grade C ("definitely declining") and HOLC grade A+B ("best + still desirable) neighborhoods and between HOLC grade D ("hazardous/redlined") and HOLC grade A+B ("best + still desirable) neighborhoods in areas with low social vulnerability (SVI) versus areas with high SVI for Black, Hispanic and White patients hospitalized for sports and recreational injuries (SRI). P-values are the values for Type III F-tests of fixed HOLC grade and SVI interaction effects. P-values ≤ 0.05 indicates statistically significant interaction effects.

4.4 Discussion

In this study, we examined the racial/ethnic disparities in the effects of historical redlining, a government-sanctioned racially discriminatory practice in the 1930s, on SRI hospitalization, length of hospital stay, and total hospital charges in the U.S. While most SRI do not result in hospitalization, our finding shows that the number of SRI that result in hospitalization is significant and can have a major health and economic burden on patients as well as the health care system.[2]

Consistent with findings from previous studies on SRI hospitalizations and ED visits, a greater proportion of younger males than older males were hospitalized for SRI.[2,23–26] This observation may be due the higher exposure of younger males to sports and recreation and their willingness to take risks.[2] Also, like previous studies on emergency department visits, this work found higher proportion of SRI hospitalization among White patients than other racial/ethnic groups.[24] The racial differences observed between White and other racial/ethnic groups could be due to differences in access to facilities and environments that encourage participation in sports and recreational activities, as increased participation carries with it an inherent risk of SRI.[27] In addition, we found that a greater proportion of Black and Hispanic patients hospitalized for SRI, compared to White patients, were uninsured and cited Medicaid as source of payment. This finding suggests a vulnerability to severe SRI for Black and Hispanic populations due to barriers in access to quality health care considering that health care access is an importance social determinant of SRI.[24]

In this study, we also found that HOLC grades were not associated with the odds of SRI hospitalization for all racial/ethnic groups but was associated with LOS for Black and Hispanic patients, and with total hospital charges per discharge for Hispanic patients. It is possible that the risk of SRI is higher for individuals living in historically redlined areas compared to those living in non-redlined areas; however, differences in healthcare seeking behavior (e.g., home care for SRI) and lack of access to adequate healthcare in formerly redlined area might explain why the odds of hospitalization is not different in redlined versus non-redlined area. The significant association observed for LOS and total charges indicates that structural racism is an important determinant of health and access to healthcare. This is consistent with other recent studies that linked historical redlining with present-day health outcomes;[10,13] however, this is the first study to our knowledge that has examined the association between indicators of structural racism, such as historical redlining, and SRI.

It is important to note that Black and Hispanic patients hospitalized in neighborhoods historically considered as "definitely declining" and "hazardous/redlined" (HOLC grade C and D) had longer LOS compared to those hospitalized in neighborhoods graded "best/still desirable" (HOLC grade A+B). This suggests that Black and Hispanic patients hospitalized in historically marginalized areas may lack access to adequate, timely, and quality health care due to the poor socioeconomic condition of their neighborhoods. For example, 62.6% of Black patients and 37.0% of Hispanic patients who were hospitalized in historically redlined areas lived in ZIP Code with the lowest median household income (< $38,999 in 2011), while less than one-half (45.8%) of Black patients and less than one-fourth (22.5%) of Hispanic patients hospitalized in neighborhoods graded "best/still desirable" lived in ZIP Code with the lowest median household income.

This above finding is similar to other studies that reported lower socioeconomic and poorer health outcomes among Black populations residing in redlined areas.[9,10] Historical redlining is associated with poor health outcomes in Black and Hispanic patients given that redlining was a racist practice that prevented economic investment in neighborhoods with significant racial/ethnic minority population, resulting in low-quality healthcare system in these neighborhoods.[8] There was no association between historical redlining and LOS for White patients. The differential effects of HOLC grades on SRI outcome among racial/ethnic minority patients and White patients highlight the importance of investigating the structural factors that captures the distinct and traumatic experiences of marginalized racial and ethnic groups in the U.S.[9]

It is also important to note that Hispanic patients hospitalized in neighborhoods historically graded as “definitely declining” had higher total hospital charges per discharge compared to those hospitalized in neighborhoods graded “best/still desirable”. This higher total charges for Hispanic patients could be related to language barrier resulting in inappropriate care for injuries, such as unnecessary MRI or CT scans, that provide little or no benefit to them. This finding suggests that interventions aimed at addressing language barrier and inappropriate injury care, including misuse or overuse of health care services, could lessen the financial burden of SRI hospitalization among Hispanic patients.[28]

To assess the role of contemporary neighborhood environment on the effect of historical redlining practices, we examined whether present-day neighborhood social vulnerability (SVI) modified the association between HOLC grade and LOS and total charges per discharge. We found that the associations between HOLC grade and LOS were modified by neighborhood SVI among Black and White patients. In high-vulnerable areas, White patients who were hospitalized in historically redlined neighborhoods had shorter LOS compared to those hospitalized in “best/still desirable” neighborhoods; while in low-vulnerable areas, there was no difference in the LOS for White patients who were hospitalized in historically redlined neighborhoods versus those hospitalized in “best/still desirable” neighborhoods.

The shorter LOS observed among White patients hospitalized in formerly redlined neighborhoods of high-vulnerable areas could be due to gentrification. Gentrification is this instance is the contemporary transformation of the characteristics of formerly redlined neighborhoods through the influx of high-income, mostly White residents.[29] For example, we found that more than one-half (55.9%) of White patients hospitalized in high-vulnerable redlined areas lived in ZIP Codes with the highest and second-highest median household income (≥ $48,000 in 2011) while less than one-half (47.5) of White patients hospitalized in high-vulnerable “best/still desirable” areas lived in ZIP Codes with the highest and second-highest median household income, indicating a transformation of formerly redlined areas. This type of transformation often results in significant investment in the neighborhood and healthcare system of the gentrified areas, resulting in better health outcomes for residents.[29] For Black patients, the LOS was longer for those hospitalized in low-vulnerable “definitely declining” area compared to those hospitalized in low-vulnerable “best/still desirable” area; however, no significant differences were observed for other comparisons. The longer LOS observed in only low-vulnerable formerly grade C areas may be due to greater experiences of discrimination in health care settings among Black patients hospitalized in low-vulnerable neighborhoods.[9] This type of discrimination in health care settings among Black middle or upper-class Americans living in low-vulnerable neighborhoods may result in poor or inappropriate treatment of their injuries leading to longer stay in hospitals. Also, the longer LOS could be due to current hospital conditions in these low-vulnerable grade C areas, such as shortages in physicians and poor health care facilities.

We also found that the associations between HOLC grade and total charges per discharge were modified by neighborhood SVI among Hispanic and White patients. In high-vulnerable areas, Hispanic and White patients who were hospitalized in neighborhood historically graded as “definitely declining” (HOLC grade C) and “hazardous” (HOLC grade D) bore a greater financial burden than those hospitalized in “best/still desirable” neighborhoods (HOLC grade A), whereas in low-vulnerable areas, Hispanic and White patients who were hospitalized in neighborhood historically graded as “definitely declining” and “hazardous” bore a lower financial burden than those hospitalized in “best/still desirable” neighborhoods. As mentioned earlier, the higher total charges could be due to language barrier that results in inappropriate injury care that provide little or no benefit to patients hospitalized in high-vulnerable areas.

This study has a few limitations. First, we used the 2011 NIS SRI hospitalization data instead of more recent data because hospital addresses, which allowed us to link NIS data with other datasets and examined the association between historical redlining and SRI, were unavailable in NIS datasets after 2011. Capturing more neighborhood characteristics in NIS data, beyond the median income of patients’ zip code, would make it possible to carry out analysis on neighborhood effects on health using more recent data. Second, we used the neighborhood characteristics where the patients were hospitalized for SRI in our analysis, but did not have data on the neighborhood characteristics where the patients live or were injured, except for data on the median household income of the patient’s zip code. This limited our ability to differentiate the effects of the neighborhood characteristics where the patients resided versus the neighborhood characteristics where the patients were hospitalized. Third, only 0.8% of patients were hospitalized in HOLC grade A neighborhoods, as a result, we combined data for HOLC grade A with HOLC grade B (i.e., grade A+B) to enable us to separately examine the associations between redlining and SRI for each racial and ethnic category. Because we combined HOLC grade A and B, we were unable to accurately capture the four HOLC grades (A, B, C, and D) as they were historically designated.

4.5 Conclusions

This is the first study to examine the effect of structural racism, including historical redlining, on SRI. Our findings provide empirical evidence for the persistent impact of historical redlining, a structural racist policy, on SRI among all racial and ethnic groups in the U.S. The results of this study suggest that policies and contextual interventions aimed at reducing the social vulnerability of communities through enforcement of anti-discrimination laws and economic investment in historically marginalized communities[31] (e.g., increasing access to quality employment, increasing access to education, increasing access to quality health care, increasing access to safe sports and recreational environment etc.) could lessen the impact of historical discriminatory practices on the physical and financial burden of SRI. Future studies should examine the role of gentrification in mediating the impact of historical redlining and other indicators of structural racism on presently-day SRI, especially among low-income racial and ethnic minorities.

Table 4.3: Description of E-codes used for identifying and selecting patients that were hospitalized due to SRI.

E-code	Description	Sports and recreation category	Specificity [j]	N (%)
E007 (.0-.7, .9)	Sports/athletics played as a group or team [a]	Individual/team sports	1	1337 (7.4)
E006(.2, .3, .6, .9), E008 (.0-.2, .4)	Sports/athletics played individually [b]	Individual/team sports	1	381 (2.1)
E886.0, E917 (.0, .5)	Fall, or struck by/striking against, in sports [c]	Individual/team sports	5	1134 (6.3)
E008.9	Other specified sports/athletic activity	Individual/team sports	4	74 (0.4)
E005 (.0, .2, .4, .9)	Dancing and other rhythmic movement [d]	Indoor/outdoor recreations/activities	1	98 (0.5)
E005.1, E001 (.0-.1), E009 (.0-.9), E010 (.0-.9)	Cardiorespiratory and muscle strengthening activities, not elsewhere specified [e]	Indoor/outdoor recreations/activities	4	3406 (18.8)
E005.3, E006.5, E007.8, E008.3, E884.0	Activities involving play and other activities usually unstructured [f]	Indoor/outdoor recreations/activities	4	697 (3.8)
E006.4, E800-E807 (.3), E810-E819 (.6), E820-E825 (.6), E826 (.1,.9), E827-E829 (.1)	Pedal cycle [g]	Indoor/outdoor recreations/activities	2	4251 (23.5)
E002 (.0-.9), E830-E838 (.0, .1, .3, .4, .5, .8, .9), E883.0, E902.2, E910 (.0, .1, .2, .8, .9)	Recreational activities involving bodies of water [h]	Indoor/outdoor recreations/activities	3	840 (4.6)
E003 (.0-.9), E004 (.0-.9), E006 (.0, .1), E820-E821 (.0, .1, .5, .8, .9), E822-E825 (.5), E826-E829 (.2), E885 (.0-.2), E922 (.4, .5)	Other outdoor recreational activities [i]	Indoor/outdoor recreations/activities	3	3356 (18.5)
E849.4	Injury occurred at a place of recreation or sport, no further detail	Other/unspecified	6	2551 (14.1)
TOTAL				18125 (100.0)

E-codes are the *International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM)*, external-cause-of injury codes. The E-code-based case definition of SRI hospitalization is based on method developed by Harmon et al. (2018).[22]

[a] Sports/athletics played as a group or team include American tackle football (E007.0), basketball (E007.6), soccer (E007.5), baseball and softball (E007.3), volleyball (E007.7), lacrosse and field hockey (E007.4), American touch/flag football (E007.1), rugby (E007.2), and other activities played as a group or team (E007.9).

[b] Sports/athletics played individually include wrestling (E008.1), martial arts (E008.4), racquet and hand sports (E008.2), golf (E006.2), boxing (E008.0), bowling (E006.3), track and field events (excludes running) (E006.6), and other activities played individually (E006.9).

[c] Fall, or struck by/striking against, in sports includes struck by/against in sports, no subsequent fall (E917.0), struck by/against in sports with subsequent fall (E917.5), and fall on same level from collision, pushing, or shoving, by or with other person in sports (E886.0).

[d] Dancing and other rhythmic movement include cheerleading (E005.4), gymnastics (E005.2), and dancing and other activity involving rhythmic movement (E005.0, E005.9).

[e] Cardiorespiratory and muscle strengthening activities, not elsewhere specified include running (E001.1), walking, hiking, and marching (E001.0), other cardiorespiratory exercise (E009 (.0-.9)), other muscle strengthening exercises (E010 (.0-.9)), and yoga (E005.1).

[f] Activities involving play and other activities usually unstructured include fall from playground equipment (E884.0), trampoline (E005.3), frisbee (E008.3), jumping rope (E006.5), and physical games generally associated with school recess, summer camp and children (E007.8).

[g] Pedal cycle includes nontraffic-related (i.e. off-road) (E800-E807 (.3), E820-E825 (.6), E826 (.1,.9), E827-E829 (.1)), traffic-related (i.e. on-road) (E810-E819 (.6)), and bike riding, unspecified (E006.4).

[h] Recreational activities involving bodies of water include waterskiing (E002.6, E910.0, E830-E838 (.4)), and other activities involving water and watercraft (E002 (.0-.5, .7-.9), E830-E838 (.0, .1, .3, .5, .8, .9), E883.0, E902.2, E910 (.1, .2, .8, .9)).

[i] Other outdoor recreational activities include roller skating and skateboarding (E006.0, E885 (.1,.2)), snow and other off-road vehicles (E820-E821 (.0, .1, .8, .9)), snow skiing, snowboarding, and other activities involving snow and ice (E003 (.0-.9), E885 (.3, .4)), animal being ridden (E006.1, E820-E825 (.5), E826-E829 (.2)), fall from non-motorized scooter (E885.0), air gun (E922 (.4, .5)), and climbing, rappelling and jumping off (E004 (.0-.9)) [*Based on Harmon et al., 2018*].

[j] Up to four E-codes describing the cause of hospitalization were collected in the HCUP NIS database. For hospitalizations with more than one E-code, we gave preference to those with more specific E-codes ("1") over those with less specific E-codes ("6"). For hospitalizations with more than one E-code of the same specificity level, we assigned cause of hospitalization based on the first-listed E-code.

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Chapter 4: Social vulnerability and traumatic brain injury hospitalizations from sports and recreation among pediatric patients in the United States

Abstract

Background: Individual and neighborhood social vulnerability are potential risk factors for sports and recreation-related traumatic brain injury (**SR-TBI**) in children; however, their effects on SR-TBI have rarely been studied.

Methods: We obtained 2009, 2010 and 2011 hospitalization data in the U.S. from the National Inpatient Sample (**NIS**) database, linked it to 2010 neighborhood social vulnerability index (**SVI**) data from the Centers for Disease Prevention and Control (**CDC**), and assigned U.S. hospitals to one of four SVI quartiles. SR-TBI outcomes studied include: hospitalization, length of stay (**LOS**), and discharge to post-acute care (**DTPAC**). Generalized linear mixed models were used to examine the associations between potential risk factors with all three SR-TBI outcomes of interest.

Results: We found associations between race/ethnicity and all SR-TBI outcomes; however, sex, primary payer, and neighborhood overall SVI were only associated with LOS, and age with LOS and odds of DTPAC. Compared to White children, Native American children had almost three times higher odds of hospitalization for SR-TBI (OR: 2.82, 95% CI: 1.30, 6.14), 27% longer LOS (β: 27.06, 95% CI: 16.56, 38.51), but 99.9% lower odds of DTPAC (OR: 0.001, 95% CI: 0.00, 0.01). Compared to children with private insurance, children with public insurance had 11% longer LOS (β: 10.83, 95% CI: 8.65, 13.05) while uninsured children had 13% shorter LOS (β: -13.19, 95% CI: -16.56, -9.69). Older age was associated with higher odds of hospitalization and longer LOS ($p < 0.0001$) while male sex was associated with shorter LOS for SR-TBI in children ($p < 0.0001$). Hospitalization in neighborhood with higher overall SVI was associated with longer LOS ($p < 0.0001$).

Conclusions: These findings suggest that individual and neighborhood social vulnerability can have a significant impact on the health outcomes of children, especially in the context of SR-TBI.

Keywords: Social vulnerability, traumatic brain injury, sports and recreation, pediatric, children, hospitalization

5.1 Background

Traumatic Brain Injury (**TBI**) is a significant public health concern in the United States, particularly among children and adolescents participating in sports and recreational activities.[1,2] According to recent report, more than 600,000 emergency department (**ED**) visits, more than 65,000 hospitalizations, and more 6,000 deaths due to TBI occurred among children and adolescents in the United States in a year.[3] Nearly half of TBI-related ED visits are due to sports and recreational activities among children and adolescents and more than two-thirds of ED visits for sports and recreation-related TBI (**SR-TBI**) are among this age group.[1] Caused by impact to the head or body or a penetrating injury, TBI hospitalizations can have devastating consequences for children, including long-term cognitive, behavioral, and physical impairments.[1]

Recent research suggests that social vulnerability may play a significant role in TBI hospitalizations among pediatric patients.[3] Social vulnerability refers to the degree to which individuals and communities are at risk of harm due to sociodemographic and socioeconomic factors such as race/ethnicity, age, poverty, low education levels, limited access to healthcare, and social isolation. Studies have found that children and adolescents from socially vulnerable backgrounds or communities are at increased risk of sustaining TBIs and experiencing adverse outcomes such as prolonged hospital stays and higher rates of mortality.[4] For instance, a recent report from the U.S. Centers for Disease Control and Prevention (CDC) shows that racial and ethnic minority children, and children who live in rural areas have higher rates of hospitalizations and deaths from TBI.[4] While a number of studies have explored the impact of individual social vulnerability, such as race/ethnicity and socioeconomic status, on TBI, only a few studies have explored this relationship for SR-TBI among pediatric patients, and no studies to date have explored the role of neighborhood social vulnerability on all SR-TBI or SR-TBI hospitalizations.[3,5]

This study explored the characteristics of patients, hospital, and neighborhood for SR-TBI hospitalizations versus non-SR-TBI hospitalizations. This study also examined the relationship between individual (i.e., race/ethnicity, age, sex and insurance status) as well as neighborhood social vulnerability (i.e., overall social vulnerability index and urban-rural location) and SR-TBI hospitalizations among pediatric patients in the United States.

5.2 Methods

5.2.1 Data collection and linkage

We obtained the 2009, 2010 and 2011 pediatric SR-TBI hospitalization data in the U.S. from the Healthcare Cost and Utilization Project (**HCUP**) National Inpatient Sample (**NIS**) database.[6] The 2009, 2010 and 2011 NIS data were used because, unlike more recent NIS data, they contained hospital addresses that enabled us to link them with other datasets with geographical information. The NIS is the largest publicly available source of all-payer inpatient care data in the U.S.[7] Unweighted, the NIS contains data from about 8 million hospitalizations per year from about a thousand hospitals across the U.S. (**Figure 5.1**). Hospitals in the NIS database were sampled to make the data a nationally representative sample of patients.[7]

Also, we obtained the 2010 social vulnerability index (**SVI**) census tract data from the Centers for Disease Prevention and Control and Agency for Toxic Substances and Disease Registry (CDC/ATSDR) website.[8] The U.S. CDC/ASTDR uses census data to determine the social vulnerability of census tracts nationwide. To compute the 2010 overall SVI, the CDC ranked every census tract based on 14 sociodemographic variables. These variables include poverty, income, unemployment, lack of high school diploma, presence of younger population (≤ 17 years), presence of older population (≥ 65 years), single-parent households, minority population, population with lesser English speaking proficiency, lack of vehicle access, crowded housing, persons living in group quarters, presence of multi-unit structures, and mobile homes.[9] SVI makes it possible to rank neighborhoods by social and socioeconomic disadvantage across the U.S., and these data were used to assign U.S. community hospitals to one of four neighborhood SVI categories (1st Quartile – lowest SVI, 2nd Quartile, 3rd Quartile, and 4th Quartile – highest SVI).

The addresses of the hospitals were geocoded using geographic information system (**GIS**) and these geocoded hospital data were then linked to the 2010 neighborhood SVI data.

All patients aged 5 to 18 who were diagnosed of TBI "(ICD-9-CM codes 800, 801, 803, 804, 850(.0–.5, .9), 851–854, 955.55, or 950(.1–.3))"[5,10] and who met the *International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM)*, external-cause-of injury codes (E-codes; ***see Table 5.3***) that were used to identify sports and recreation-related injury in the 2009, 2010 and 2011 NIS database were selected for analysis.

5.2.2 Statistical analysis

Weighted descriptive statistics were used to characterize pediatric TBI hospitalizations from sports and recreation in 2009, 2010 and 2011 with respect to individual confounders (*see* **Table 5.1**). Categorical variables were described using frequencies and percentages while continuous and count variables were described using means, standard deviations (**SD**), medians, and ranges (minimum, maximum). Total hospital charges were adjusted for inflation based on the 2011 levels using the consumer price index inflation calculator of the U.S. Bureau of Labor Statistics.[11]

Generalized linear mixed models (**GLMMs**) were used to examine the associations between individual social vulnerability (race/ethnicity, age, sex, and primary payer), neighborhood social vulnerability (overall SVI, urban-rural location), and SR-TBI hospitalization, length of stay (**LOS**), and discharge to post-acute care (**DTPAC**) among pediatric patients. SR-TBI hospitalization and DTPAC were a binary outcome and therefore was modeled using a GLMM specifying a binomial distribution while LOS was an over-dispersed count outcome variable and thus was modeled using GLMMs specifying negative binomial distributions. DTPAC included discharge or transfer to short-term hospital, skilled nursing facility, intermediate care facility, other type of facility (e.g., rehabilitation facility), and home health care. Patients with minor SR-TBI severity and patients that died were excluded from the post-acute care analysis. All models were two-level GLMMs with a random intercept to account for the nesting of patients within hospital neighborhoods. Sample weights and stratified sampling were also accounted for in the GLMMs. A Bonferroni adjustment was used to account for multiplicity due to three study outcomes and therefore, statistical significance was taken at the $\alpha = 0.0167$ level. All analyses were conducted using SAS Version 9.4 (SAS Institute Inc., Cary, NC) and ArcGIS Pro.

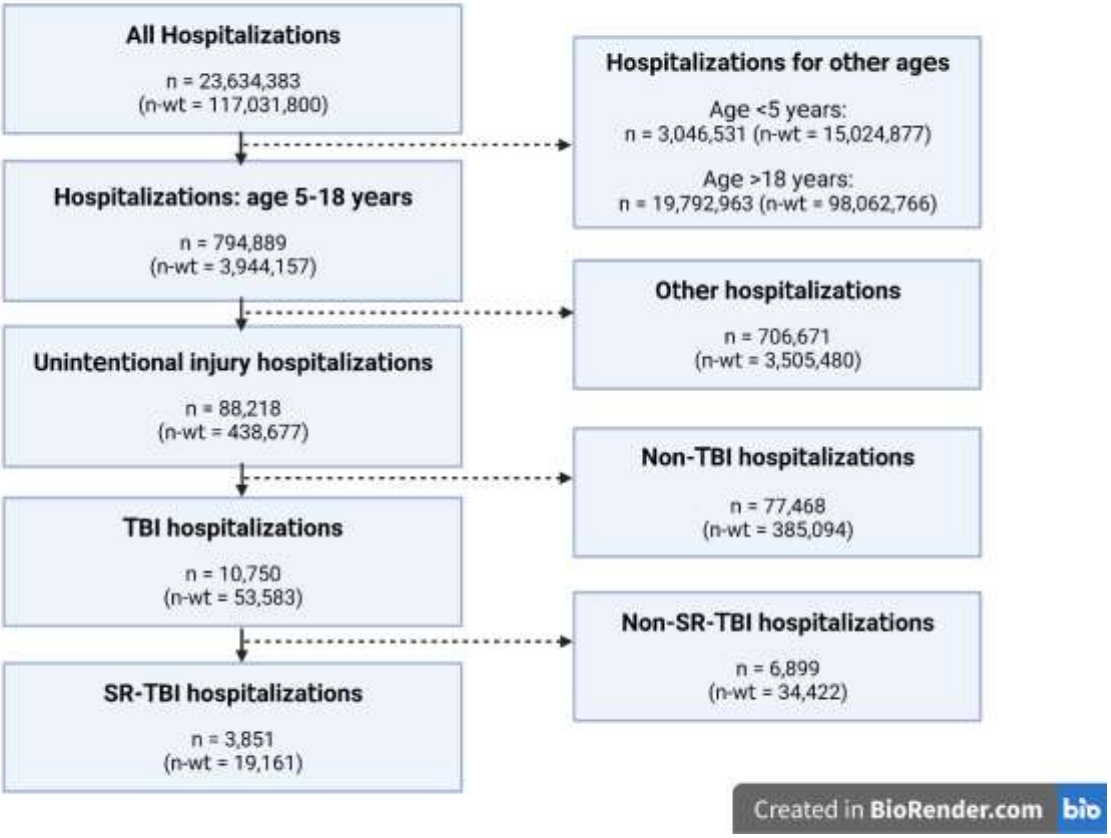

Figure 5.1: Flow diagram of hospitalizations in the U.S. (NIS, 2009-2011)

5.3 Results

5.3.1 Characteristics of traumatic brain injury hospitalizations in pediatric patients

Table 5.1 contains patient, hospital, and neighborhood characteristics of TBI hospitalizations among pediatric patients in the U.S. A total of 10,750 unintentional TBI hospitalizations were identified in the NIS data sample, representing an estimated weighted total of 55,584 unintentional TBI hospitalizations in the U.S. from 2009 to 2011. More than one-thirds (19,161) of unintentional TBI hospitalizations were due to participation in sports and recreational activities.

Patients and neighborhood characteristics for TBI hospitalizations differed between SR-TBI and non-SR-TBI (**Table 5.1**). Compared to children hospitalized for non-SR-TBI, children hospitalized for SR-TBI were more likely to be male (SR-TBI: 76.9%; non-SR-TBI: 65.7), White (SR-TBI: 68.6%; non-SR-TBI: 59.1%), and younger than age 15 (SR-TBI: 59.9%; non-SR-TBI: 45.4). They were also more likely to cite private insurance as source of payment (SR-TBI: 63.0%; non-SR-TBI: 57.0%), and to live in zip code with the highest median household income (SR-TBI: 26.6%; non-SR-TBI: 20.2%); but were less likely to live in urban areas (SR-TBI: 95.0%; non-SR-TBI: 96.1%), to be hospitalized in neighborhoods with highest overall social vulnerability (SR-TBI: 35.0%; non-SR-TBI: 37.4%), and to have alcohol use disorder (SR-TBI: 1.3%; non-SR-TBI: 5.3%) and substance use disorder (SR-TBI: 1.5%; non-SR-TBI: 4.2%) compared to children hospitalized for non-SR-TBI. The main source of admission for children with unintentional TBI was emergency department (SR-TBI: 68.7%; non-SR-TBI: 71.0%); however, children hospitalized for SR-TBI were less likely to suffer from extremely severe TBI (SR-TBI: 4.4%; non-SR-TBI: 13.8%) or die from TBI (SR-TBI: 1.2%; non-SR-TBI: 4.9%) compared to children hospitalized for non-SR-TBI. Also, a greater proportion of SR-TBI hospitalizations in pediatric patients occurred in summer (June – August; 31.7%), and most of the patients were hospitalized in large (72.5%) and teaching hospitals (79.7%) than in smaller and non-teaching hospitals.

Table 5.1 also contains summary statistics for LOS and total charges per discharge. The average LOS was significantly shorter for children hospitalized for SR-TBI (2.85 days) compared to those hospitalized for non-SR-TBI (5.10 days) [p < 0.0001]. Similarly, the total charges per discharge was significantly lower for children hospitalized for SR-TBI (US$ 35,437) compared to those hospitalized for non-SR-TBI (US$ 62,285) [p < 0.0001].

Table 5.1: Patient, hospital, and neighborhood characteristics of unintentional traumatic brain injury hospitalizations among pediatric patients in the U.S., NIS 2009-2011

Characteristics	**SR-TBI hospitalization**	**Other TBI hospitalization**	**Total TBI hospitalization**	**P-value**
	(n = 19,161)	**(n = 34422)**	**(n = 53584)**	
Age, n (%)				<0.0001
5 - 9	3874 (20.2)	8063 (23.4)	11937 (22.3)	
10 - 14	7608 (39.7)	7575 (22.0)	15183 (28.3)	
15 - 18	7680 (40.1)	18784 (54.6)	26464 (49.4)	
Sex, n (%)				<0.0001
Female	4376 (23.1)	11715 (34.3)	16091 (30.3)	
Male	14594 (76.9)	22452 (65.7)	37046 (69.7)	
Race, n (%)				<0.0001
Asian/Pacific Islander	323 (1.9)	637 (2.1)	960 (2.0)	
Black	1577 (9.4)	4340 (14.3)	5916 (12.6)	
Hispanic	2513 (15.0)	5518 (18.2)	8031 (17.1)	
Native American	193 (1.2)	467 (1.5)	660 (1.4)	
Other	651 (3.9)	1449 (4.8)	2100 (4.5)	
White	11461 (68.6)	17915 (59.1)	29376 (62.4)	
Payer information, n (%)				<0.0001
Medicaid	4959 (25.9)	10332 (30.1)	15291 (28.6)	
Medicare	104 (0.6)	155 (0.5)	259 (0.5)	
No charge/Other	921 (4.8)	1972 (5.8)	2892 (5.4)	
Private insurance	12075 (63.0)	19559 (57.0)	31634 (59.2)	
Self-pay	1094 (5.7)	2269 (6.6)	3362 (6.3)	
Median household income for patient's ZIP Code, n (%)				<0.0001
1st Quartile ($1 - $38,999)	4019 (21.7)	9518 (28.5)	13538 (26.1)	
2nd Quartile ($39,000 - $47,999)	4381 (23.6)	8577 (25.7)	12958 (24.9)	
3rd Quartile ($48,000 - $63,999)	5235 (28.2)	8552 (25.6)	13787 (26.5)	
4th Quartile (≥ $64,000)	4930 (26.6)	6728 (20.2)	11658 (22.4)	
Alcohol use disorder, n (%)				<0.0001
No	18910 (98.7)	32581 (94.7)	51491 (96.1)	
Yes	252 (1.3)	1841 (5.3)	2093 (3.9)	
Substance use disorder, n (%)				<0.0001
No	18870 (98.5)	32987 (95.8)	51857 (96.8)	
Yes	291 (1.5)	1435 (4.2)	1726 (3.2)	
Obesity, n (%)				0.7129
No	19032 (99.3)	34172 (99.3)	53204 (99.3)	
Yes	129 (0.7)	250 (0.7)	379 (0.7)	
Admission year, n (%)				0.2995
2009	6398 (33.4)	12278 (35.7)	18676 (34.8)	
2010	7880 (41.1)	13533 (39.3)	21413 (40.0)	
2011	4884 (25.5)	8611 (25.0)	13495 (25.2)	
Admission month/season, n (%)				0.0002
Sept. - Nov. (Fall)	4329 (24.2)	7712 (24.3)	12041 (24.3)	
March - May (Spring)	5063 (28.3)	8652 (27.3)	13715 (27.7)	
June - Aug. (Summer)	5659 (31.7)	9170 (28.9)	14829 (29.9)	
Dec. - Feb. (Winter)	2816 (15.8)	6189 (19.5)	9005 (18.2)	
Admission day, n (%)				0.4781
Mon. - Fri. (Weekday)	12665 (66.1)	22501 (65.4)	35166 (65.6)	
Sat. - Sun. (Weekend)	6496 (33.9)	11922 (34.6)	18418 (34.4)	
Teaching status of hospital, n (%)				0.0597
Nonteaching	3788 (20.3)	5904 (17.8)	9692 (18.7)	
Teaching	14916 (79.7)	27208 (82.2)	42124 (81.3)	

Characteristics	**SR-TBI hospitalization**	**Other TBI hospitalization**	**Total TBI hospitalization**	**P-value**
	(n = 19,161)	**(n = 34422)**	**(n = 53584)**	
Bedsize of hospital, n (%)				0.0442
Large	13552 (72.5)	25227 (76.2)	38779 (74.8)	
Medium	4147 (22.2)	6214 (18.8)	10361 (20.0)	
Small	1005 (5.4)	1671 (5.0)	2676 (5.2)	
Disposition of patients, n (%)				<0.0001
Routine discharge	17769 (92.7)	27408 (79.7)	45177 (84.3)	
Discharge to post-acute care care	1122 (5.9)	5165 (15.0)	6287 (11.7)	
Died	226 (1.2)	1682 (4.9)	1908 (3.6)	
Other	44 (0.2)	153 (0.4)	197 (0.4)	
Admission source, n (%)				0.6392
Emergency department	2848 (68.7)	4657 (71.0)	7504 (70.1)	
Routine/other	965 (23.3)	1442 (22.0)	2407 (22.5)	
Transfer	335 (8.1)	460 (7.0)	795 (7.4)	
Injury type, n (%)				
Individual/team sports	4686 (24.7)	-	-	
Recreational activities	12857 (67.8)	-	-	
Other	1411 (7.5)	-	-	
Injury type, n (%)				0.0815
Fracture	7637 (39.9)	14423 (41.9)	22060 (41.2)	
Internal organ	11524 (60.1)	19999 (58.1)	31523 (58.8)	
Injury severity, n (%)				<0.0001
Minor	10453 (54.6)	13272 (38.6)	23725 (44.3)	
Moderate	5944 (31.0)	10657 (31.0)	16601 (31.0)	
Serious	1929 (10.1)	5749 (16.7)	7678 (14.3)	
Severe	835 (4.4)	4744 (13.8)	5579 (10.4)	
Hospital location				0.0338
Rural	937 (5.0)	1307 (3.9)	2244 (4.3)	
Urban	17767 (95.0)	31805 (96.1)	49573 (95.7)	
Hospital census region				<0.0001
Midwest	3186 (16.6)	6107 (17.7)	9293 (17.3)	
Northeast	4055 (21.2)	7501 (21.8)	11556 (21.6)	
South	5757 (30.0)	12130 (35.2)	17887 (33.4)	
West	6163 (32.2)	8684 (25.2)	14848 (27.7)	
Overall social vulnerability				0.0309
1st Quartile	2295 (16.6)	3000 (12.9)	5295 (14.3)	
2nd Quartile	3214 (23.3)	6020 (25.9)	9235 (24.9)	
3rd Quartile	3475 (25.1)	5521 (23.8)	8996 (24.3)	
4th Quartile	4833 (35.0)	8699 (37.4)	13532 (36.5)	
Length of hospital stay (days)				<0.0001
mean±SEM	2.85 (0.11) [a]	5.10 (0.18) [b]	4.29 (0.15)	
median (q1, q3)	0.99 (0.41, 2.34)	1.58 (0.57, 4.00)	1.35 (0.50, 3.31)	
min, max	0, 111	0, 316	0, 316	
Total charges per discharge (USD)				<0.0001
mean±SEM	35437 (2720.26) [a]	62285 (2767.69) [b]	52714 (2572.23)	
median (q1, q3)	17766 (9110, 34939)	26744 (13257, 57112)	22912 (11378, 47395)	
min, max	113, 2217529	171, 1988700	113, 2217529	

P-values are based on chi-square tests and one-way analysis of variance (ANOVA) for categorical and discrete variables, respectively. For the ANOVA, length of hospital stay and total hospital charges were log-transformed to meet the statistical assumption of normality. Tukey's test was used for pairwise mean comparison of length of stay and total charges for SR-TBI versus non-SR-TBI. Means with different letters are significantly different from each other.

5.3.2 Association between individual and neighborhood social vulnerability, and SR-TBI hospitalization, length of stay and discharge to post-acute care

Table 5.2 summarizes the adjusted association between individual as well as neighborhood vulnerability characteristics and SR-TBI hospitalization, LOS and DTPAC. No statistically significant associations were observed between male and female pediatric patients with the odds of hospitalization and DTPAC for SR-TBI ($p > 0.0167$), but the LOS was 5.36% shorter for male than female pediatric patients hospitalized for SR-TBI ($\beta = -5.36$, 95% CI: -7.10, -3.58; $p < 0.0001$).

Compared to children aged 5-9 years, children aged 10-14 and 15-18 years had 53% and 43% higher odds of SR-TBI hospitalization, respectively (10-14 years: OR = 1.53, 95% CI: 1.33 1.76; 15-19 years: OR = 1.43, 95% CI: 1.19, 1.72). They also had 20.45% ($\beta = 20.45$, 95% CI: 17.79, 23.18) and 30.54% ($\beta = 30.54$, 95% CI: 27.37, 33.78) longer LOS compared to children aged 5-9 years; however, their odds of DTPAC was not significantly different from those of children aged 5-9 years ($p > 0.0167$).

We found a significant association between race/ethnicity and the odds of SR-TBI hospitalization, odds of DTPAC, and LOS ($p \leq 0.0167$). Compared to White children, Black children had 27% lower odds of hospitalization (OR = 0.73, 95% CI: 0.58, 0.92), while Native American children had about three times higher odds of hospitalization for SR-TBI (OR = 2.82, 95% CI: 1.30, 6.14). Similarly, compared to White children, Native American children had 27.06% longer LOS ($\beta = 27.06$, 95% CI: 16.56, 38.51) while Hispanic children had 8.22 % longer LOS ($\beta = 8.22$, 95% CI: 5.63, 10.88). In contrast to the higher odds of hospitalization and longer LOS, Native American children had 99.9% lower odds of DTPAC for SR-TBI (OR = 0.001, 95% CI: <0.001, 0.01). There was no significant difference in the odds of SR-TBI hospitalization between White and Asian/Pacific Islander and between White and Hispanic children ($p > 0.0167$). Also, LOS was not significantly different between White and Asian/Pacific Islander and between White and Black children ($p > 0.0167$). In addition, there was no significant difference in the odds of DTPAC between White and the other racial/ethnic minority children ($p > 0.0167$).

Also, we found no significant association between primary payer and the odds of SR-TBI hospitalization and between primary payer and the odds of DTPAC ($p > 0.0167$); however, significant association was observed between primary payer and LOS ($p \leq 0.0167$). Compared to children whose source of payment were private insurance, children whose source of payment were public insurance had 10.83% ($\beta = 10.83$, 95% CI: 8.65, 13.05) longer LOS, while children who were uninsured had 13.19% ($\beta = -13.19$, 95% CI: -16.56, -9.69) shorter LOS for SR-TBI.

For neighborhood factors, there was no statistically significant difference in the odds of hospitalization, length of hospital stay, and the odds of DTPAC for SR-TBI between pediatric patients who were hospitalized in urban areas versus rural areas ($p > 0.0167$). Also, we found no significant association between neighborhood overall SVI and the odds of SR-TBI hospitalization and between overall SVI and the odds of DTPAC ($p > 0.0167$); however, significant association was observed between overall SVI and LOS ($p \leq 0.0167$). Compared to children who were hospitalized in neighborhoods with the lowest overall SVI category (1st Quartile SVI), children who were hospitalized in neighborhoods with the second lowest (2nd Quartile SVI), next to the highest (3rd Quartile SVI), and highest overall SVI category (4th Quartile) had 11.33% ($\beta = 11.33$, 95% CI: 1.94, 21.57), 18.90% ($\beta = 18.90$, 95% CI: 9.16, 29.51) and 22.68% ($\beta = 22.68$, 95% CI: 12.59, 33.68) longer LOS.

Table 5.2: Adjusted association between individual as well as neighborhood social vulnerability, and SR-TBI hospitalizations and length of hospital stay

Variables	**SR-TBI hospitalization**		**Discharge to post-acute care**		**Length of hospital stay**	
	(n = 8540; nSR-TBI=1940)		(n = 861; nPAC=111)		(n = 1940)	
	OR (95% CI)	p-value	OR (95% CI)	p-value	% Change (95% CI)	p-value
Individual-level social vulnerability						
Sex						
Female	Reference		Reference		Reference	
Male	1.09 (0.93, 1.28)	0.3021	1.37 (0.61, 3.06)	0.4480	-5.36 (-7.10, -3.58)	<0.0001
Age		*<0.0001*		*0.3466*		*<0.0001*
5-9	Reference		Reference		Reference	
10-14	1.53 (1.33, 1.76)	<0.0001	1.43 (0.44, 4.71)	0.5532	20.45 (17.79, 23.18)	<0.0001
15-18	1.43 (1.19, 1.72)	0.0002	2.36 (0.69, 8.01)	0.1694	30.54 (27.37, 33.78)	<0.0001
Race/ethnicity		*0.0096*		*<0.0001*		*<0.0001*
White	Reference		Reference		Reference	
Asian/Pacific Islander	0.91 (0.63, 1.32)	0.6230	3.80 (0.80, 18.13)	0.0938	1.93 (-2.81, 6.89)	0.4313
Black	0.73 (0.58, 0.92)	0.0064	3.37 (0.58, 19.74)	0.1774	2.44 (-0.74, 5.73)	0.1333
Hispanic	0.91 (0.66, 1.25)	0.5584	1.07 (0.44, 2.58)	0.8859	8.22 (5.63, 10.88)	<0.0001
Native American	2.82 (1.30, 6.14)	0.0089	0.001 (0.00, 0.01)	<.0001	27.06 (16.56, 38.51)	<0.0001
Other	0.84 (0.63, 1.11)	0.2097	0.18 (0.03, 1.29)	0.0873	-11.01 (-15.11, -6.71)	<0.0001
Primary payer		*0.2792*		*0.1629*		*<0.0001*
Private Insurance	Reference		Reference		Reference	
Public Insurance	0.97 (0.81, 1.15)	0.7327	2.00 (0.82, 4.84)	0.1262	10.83 (8.65, 13.05)	<0.0001
Other	1.20 (0.87, 1.65)	0.2703	2.33 (0.64, 8.49)	0.1993	23.24 (19.01, 27.65)	<0.0001
Uninsured	1.22 (0.91, 1.63)	0.1892	0.45 (0.09, 2.19)	0.3249	-13.19 (-16.56, -9.69)	<0.0001
Neighborhood-level social vulnerability						
Location						
Rural	Reference					
Urban	1.67 (0.86, 3.23)	0.1310	0.47 (0.02, 10.29)	0.6319	9.14 (0.27, 18.80)	0.0432
Overall social vulnerability index (SVI)		*0.1667*		*0.8168*		*<0.0001*

Variables	**SR-TBI hospitalization**		**Discharge to post-acute care**		**Length of hospital stay**	
	(n = 8540; nSR-TBI=1940)		(n = 861; nPAC=111)		(n = 1940)	
	OR (95% CI)	p-value	OR (95% CI)	p-value	% Change (95% CI)	p-value
1st Quartile	Reference		Reference		Reference	
2nd Quartile	1.19 (0.60, 2.34)	0.6193	2.54 (0.34, 18.84)	0.3634	11.33 (1.94, 21.57)	0.0169
3rd Quartile	0.85 (0.44, 1.66)	0.6364	1.19 (0.16, 8.59)	0.8649	18.90 (9.16, 29.51)	<.0001
4th Quartile	1.51 (0.77, 2.95)	0.2330	1.55 (0.23, 10.32)	0.6496	22.68 (12.59, 33.68)	<.0001

OR: Odds Ratio – represents a binary outcome for the odds of being hospitalized for SR-TBI versus the odds of not being hospitalized for SR-TBI, and for the odds of being discharge to post-acute care versus the odds of not being discharge to post-acute care for SR-TBI. % change (95% CI) was calculated using $[(\exp(\beta) - 1) * 100]$ where β is the regression coefficient of individual and neighborhood social vulnerability for length of stay with negative binomial distribution (log link). CI: Confidence Interval; Italicized p-values are the values of the Type III F-tests. P-values ≤ 0.0167 indicate statistically significant effects because models were adjusted for multiplicity due to three primary outcomes (i.e., P = 0.05/3 = 0.0167). Models are adjusted for median household income of patient's ZIP Code, alcohol-use disorder, substance-use disorder, obesity comorbidity status, admission year, admission month/season, admission day, injured body region, injury type, injury severity, number of registered nurses per 1000 adjusted inpatient days, teaching status of hospital, bed size of hospital, hospital's census region, and hospital location. n – is the total number of patients used for analysis; nSR-TBI – is the number of patients with SR-TBI; nPAC – is the number of patients discharge to post-acute care.

5.4 Discussion

In this study, we explored the characteristics of patients, hospital, and neighborhood for SR-TBI hospitalization versus non-SR-TBI hospitalization, and examined the relationship between individual as well as neighborhood social vulnerability and SR-TBI hospitalizations among pediatric patients in the United States. We found significant difference between SR-TBI and non-SR-TBI hospitalizations based on patients' (e.g., age, sex, race/ethnicity, and payer information) and neighborhood vulnerability characteristics (e.g., urban-rural location, and overall social vulnerability. This highlights the importance of capturing and distinguishing between sports and non-sports mechanisms of TBI and investigating risk factors that are associated with them.

We also found that sex was not associated with both the odds of SR-TBI hospitalization and the odds of DTPAC, but was associated with the LOS in pediatric patients. Male sex was protective against longer LOS. Our finding on the odds of SR-TBI hospitalization is consistent with the finding of Yang et al. (2008)[5] but it is contrary to a recent study that reported higher risk of SR-TBI among male patients.[1] This is the first study to examine the associations between sex and LOS, and between sex and DTPAC for pediatric patients hospitalized for SR-TBI; therefore, future studies investigating these associations in other context and age categories is necessary.

In addition, we found that older age was associated with increased odds of SR-TBI hospitalization and longer LOS in pediatric patients. This finding is likely due to the greater participation of older children in sports and recreational activities, and suggests that instituting SR-TBI prevention strategies for children during this period of increasing involvement in sports and recreation could be an vital step in preventing initial SR-TBI and in protecting children from repeated brain trauma.[1,5]

Race/ethnicity was significantly associated with all three SR-TBI outcomes. The odds of hospitalization were higher and the LOS was longer in Native American children compared to White children, whereas the odds of DTPAC in Native American children was significantly lower. LOS was also longer in Hispanic children compared to White children. This finding is consistent with the report of the U.S. CDC that Native American children have higher risks of TBI hospitalizations than other racial/ethnic groups, and that racial/ethnic minoritized groups are more likely to have poor health outcome but are less likely to receive adequate care after sustaining a TBI than non-Hispanic White individuals.[4] Challenges in accessing appropriate healthcare might be contributing to the disparities observed among Native American and Hispanic children.[4] The odds of SR-TBI hospitalization was lower in Black children compared to White children. This finding could be due to disparity in participation in sports and recreational activities, which could partly be due to sociocultural factors as well as the availability of physical education and neighborhood infrastructure.[3]

Consistent with the finding of Yang et al. (2008)[5], health insurance status was not associated with the odds of SR-TBI hospitalization in pediatric patients. Health insurance status was also not associated with the odds of DTPAC, but was associated with the LOS. Pediatric patients whose source of payment were public insurance (Medicaid and Medicare) had longer LOS compared to those whose source of payment were private insurance, whereas pediatric patients who were uninsured had shorter LOS compared to those whose source of payment were private insurance. According to the U.S. CDC, individuals with lower incomes, such as those with public health insurance and those who are uninsured, experience significant challenges in accessing appropriate care for TBI.[4] Lack of appropriate care for low-income brain-injured children can increase their LOS in hospital; however, families of uninsured children could try to cut cost by reducing the length of hospitalization. Reducing disparities associated with SR-TBI hospitalization in children will include increasing access to health insurance and quality healthcare, and increasing training programs to educate and support healthcare providers to reduce biases experienced by racial/ethnic minority groups during hospitalization.[4]

Higher neighborhood social vulnerability was associated with longer LOS for SR-TBI in pediatric patients. While no studies to date have examined neighborhood-level social determinants of SR-TBI, this finding is consistent with those of Miller et al. (2023) who found that higher neighborhood deprivation was associated with greater burden of TBI-related symptoms during the first six months following a TBI.[12] Higher neighborhood social vulnerability or deprivation is often associated with lower access to clinical care, and less comprehensive and therapeutic services.[13] These findings suggest that neighborhood social vulnerability can have a significant impact on the health outcomes of children, especially in the context of SR-TBI.

This study has some limitations. First, we used the 2009, 2010 and 2011 NIS hospitalization data instead of more recent data because hospital addresses, which enabled us to link the data with the CDC SVI data, were not present in NIS datasets after 2011. Including additional contextual characteristics in the NIS data, beyond median household income, would ensure that researchers are able to investigate contextual or community effects on health using more recent data. Second, the characteristics of the context where the patients were hospitalized was used in our analysis instead of the context where they live or were injured. This prevented us from being able to differentiate the effects of the context where the children resided versus the context where they were hospitalized.

In conclusion, our findings provide empirical evidence to support the negative effects of neighborhood vulnerability on children's health outcomes. The results of this study suggest that the negative impact on SR-TBI could be reduced through policies and interventions targeted at increasing economic investment in socially vulnerable communities. Future studies should examine the role of present-day neighborhood social vulnerability in mediating or moderating the impact of structural racism and historical neighborhood vulnerability, including historical redlining, on presently-day SR-TBI.

Table 5.3: Description of E-codes used for identifying and selecting patients that were hospitalized due to sports and recreation-related traumatic brain injuries (SR-TBI). E-codes are the *International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM),* external-cause-of injury codes. The E-code-based case definition of SR-TBI hospitalization is based on method developed by Harmon et al. (2018).[14]

E-code	**Description**	**Sports and recreation category**	**Specificity [j]**	**N (%)**
E007 (.0-.7, .9)	Sports/athletics played as a group or team [a]	Individual/team sports	1	1376 (7.3)
E006(.2, .3, .6, .9), E008 (.0-.2, .4)	Sports/athletics played individually [b]	Individual/team sports	1	475 (2.5)
E886.0, E917 (.0, .5)	Fall, or struck by/striking against, in sports [c]	Individual/team sports	5	2754 (14.5)
E008.9	Other specified sports/athletic activity	Individual/team sports	4	82 (0.4)
E005 (.0, .2, .4, .9)	Dancing and other rhythmic movement [d]	Indoor/outdoor recreations/activities	1	62 (0.3)
E005.1, E001 (.0-.1), E009 (.0-.9), E010 (.0-.9)	Cardiorespiratory and muscle strengthening activities, not elsewhere specified [e]	Indoor/outdoor recreations/activities	4	601 (3.2)
E005.3, E006.5, E007.8, E008.3, E884.0	Activities involving play and other activities usually unstructured [f]	Indoor/outdoor recreations/activities	4	779 (4.1)
E006.4, E800-E807 (.3), E810-E819 (.6), E820-E825 (.6), E826 (.1,.9), E827-E829 (.1)	Pedal cycle [g]	Indoor/outdoor recreations/activities	2	5308 (28.0)
E002 (.0-.9), E830-E838 (.0, .1, .3, .4, .5, .8, .9), E883.0, E902.2, E910 (.0, .1, .2, .8, .9)	Recreational activities involving bodies of water [h]	Indoor/outdoor recreations/activities	3	351 (1.9)
E003 (.0-.9), E004 (.0-.9), E006 (.0, .1), E820-E821 (.0, .1, .5, .8, .9), E822-E825 (.5), E826-E829 (.2), E885 (.0-.2), E922 (.4, .5)	Other outdoor recreational activities [i]	Indoor/outdoor recreations/activities	3	5756 (30.4)
E849.4	Injury occurred at a place of recreation or sport, no further detail	Other/unspecified	6	1411 (7.4)
TOTAL				18955 (100.0)

[a] Sports/athletics played as a group or team include American tackle football (E007.0), basketball (E007.6), soccer (E007.5), baseball and softball (E007.3), volleyball (E007.7), lacrosse and field hockey (E007.4), American touch/flag football (E007.1), rugby (E007.2), and other activities played as a group or team (E007.9).

[b] Sports/athletics played individually include wrestling (E008.1), martial arts (E008.4), racquet and hand sports (E008.2), golf (E006.2), boxing (E008.0), bowling (E006.3), track and field events (excludes running) (E006.6), and other activities played individually (E006.9).

[c] Fall, or struck by/striking against, in sports includes struck by/against in sports, no subsequent fall (E917.0), struck by/against in sports with subsequent fall (E917.5), and fall on same level from collision, pushing, or shoving, by or with other person in sports (E886.0).

[d] Dancing and other rhythmic movement include cheerleading (E005.4), gymnastics (E005.2), and dancing and other activity involving rhythmic movement (E005.0, E005.9).

[e] Cardiorespiratory and muscle strengthening activities, not elsewhere specified include running (E001.1), walking, hiking, and marching (E001.0), other cardiorespiratory exercise (E009 (.0-.9)), other muscle strengthening exercises (E010 (.0-.9)), and yoga (E005.1).

[f] Activities involving play and other activities usually unstructured include fall from playground equipment (E884.0), trampoline (E005.3), frisbee (E008.3), jumping rope (E006.5), and physical games generally associated with school recess, summer camp and children (E007.8).

[g] Pedal cycle includes nontraffic-related (i.e. off-road) (E800-E807 (.3), E820-E825 (.6), E826 (.1,.9), E827-E829 (.1)), traffic-related (i.e. on-road) (E810-E819 (.6)), and bike riding, unspecified (E006.4).

[h] Recreational activities involving bodies of water include waterskiing (E002.6, E910.0, E830-E838 (.4)), and other activities involving water and watercraft (E002 (.0-.5, .7-.9), E830-E838 (.0, .1, .3, .5, .8, .9), E883.0, E902.2, E910 (.1, .2, .8, .9)).

[i] Other outdoor recreational activities include roller skating and skateboarding (E006.0, E885 (.1,.2)), snow and other off-road vehicles (E820-E821 (.0, .1, .8, .9)), snow skiing, snowboarding, and other activities involving snow and ice (E003 (.0-.9), E885 (.3, .4)), animal being ridden (E006.1, E820-E825 (.5), E826-E829 (.2)), fall from non-motorized scooter (E885.0), air gun (E922 (.4, .5)), and climbing, rappelling and jumping off (E004 (.0-.9)) [*Based on Harmon et al., 2018*].

[j] Up to four E-codes describing the cause of hospitalization were collected in the HCUP NIS database. 6"). For hospitalizations with more than one E-code, we gave preference to those with more specific E-codes ("1") over those with less specific E-codes ("6"). For hospitalizations with more than one E-code of the same specificity level, we assigned cause of hospitalization based on the first-listed E-code.

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Chapter 6: Conclusions

6.1 Summary

In Chapter 2, we systematically reviewed studies that examined the relationships between neighborhood characteristics and SRI using multilevel modeling approach. Findings from this review provided evidence that neighborhood-level factors, in addition to individual-level factors, should be taken into consideration when developing public health policies for injury prevention. In Chapter 3, we examined the association between historical redlining and present-day neighborhood social vulnerability in the United States. This study indicates that historical redlining, an indicator of structural racism, has a lasting impact on neighborhood social vulnerability. Therefore, to increase health equity and environmental justice, it is important to address the structural factors associated with higher neighborhood social vulnerability. In Chapter 4, we examined the racial/ethnic disparities in the association between historical redlining and present-day SRI hospitalization, length of stay (**LOS**), and total hospital charges in the United States. This study indicates that redlining has a lasting effect on LOS and total charges among racial/ethnic minority patients. The results of this study suggest that policies and contextual interventions aimed at reducing the social vulnerability of communities through enforcement of anti-discrimination laws and economic investment in historically marginalized communities could lessen the impact of historical discriminatory practices on the physical and financial burden of SRI. In Chapter 5, we examine the association between social vulnerability and sports and recreation-related traumatic brain injury (**SR-TBI**) hospitalization in children. The results of this study suggest that the negative impact of social vulnerability on SR-TBI could be reduced through policies and interventions targeted at increasing economic investment in socially vulnerable communities.

Historical redlining has increased the vulnerability of neighborhoods presently. These neighborhoods often lack the necessary resources for sports and recreation facilities, potentially leading to higher rates of injuries, including traumatic brain injuries (**TBI**), among residents. The long-term impact of redlining on social vulnerability and its correlation with hospitalizations due to SRI and SR-TBI underscores the need for addressing the systemic inequalities and disparities that continue to persist in historically redlined neighborhoods.

Efforts should be made to address social vulnerability and promote health equity in these neighborhoods. This includes improving access to sports and recreation facilities, promoting safe practices in sports and recreational activities, and increasing awareness and education about TBI. Additionally, addressing the underlying social determinants of health, such as poverty, lack of access to quality education, employment opportunities, and healthcare, is crucial in addressing the root causes of SRI disparities in historically redlined neighborhoods. By addressing these systemic issues and promoting health equity, we can work towards reducing hospitalizations due to SRI, including SR-TBI, in historically marginalized communities, and promoting healthier and more equitable neighborhoods throughout the United States.

Overall, it is essential to recognize and address the interconnectedness between historical redlining, social vulnerability, and health outcomes to achieve more equitable and inclusive communities.

6.2 Direction for future research

This is the first study to examine the effects of historically redlining on SRI. Findings from this dissertation presents some areas for future research. First, we used the 2009, 2010 and 2011 HCUP NIS data for our analysis in Chapters 4 and 5 because hospital addresses, which allowed us to link NIS data with other datasets that included key geographical information, were unavailable in NIS datasets after 2011. Therefore, future studies should examine the impact of historical redlining and present-day social vulnerability on SRI using more recent SRI datasets that include key geographical information. Second, I examined the impact of historical redlining on SRI hospitalizations in Chapter 2. It should be noted that most cases of SRI do not result in hospitalization. Therefore, future studies should examine the impact of redlining on SRI that result in emergency department visits and other cases of SRI that do not require visiting a healthcare provider so as to capture more cases of these injuries and to evaluate if the effects of redlining on other SRI categories will differ. Another area of potential research is to examine the effects of redlining and other indicator of structural racism on more specific types of SRI such as TBI and anterior cruciate ligament (**ACL**) injuries.

Appendix A: Supplementary tables for chapter two.

Table A1: Average overall social vulnerability index (SVI) scores for U.S. urban areas or cities grouped by HOLC grades among all HOLC neighborhood polygons that overlapped 1940 U.S. Census tracts. D-A is the difference between SVI for HOLC grades A and D neighborhoods within an urban area. An urban area with a white cell without overall SVI score does not have SVI score for that particular HOLC grade. Darker green colors indicate lower average overall SVI scores while darker red colors indicate higher average overall SVI scores.

City	State	Overall SVI (A)	Overall SVI (B)	Overall SVI (C)	Overall SVI (D)	D-A (Overall SVI)
Akron	OH	0.40	0.48	0.62	0.73	0.33
Arlington	MA			0.25		
Atlanta	GA	0.16	0.31	0.38	0.55	0.38
Atlantic City	NJ		0.83	0.92	0.98	
Augusta	GA	0.36	0.45	0.61	0.77	0.41
Austin	TX	0.17	0.30	0.41	0.25	0.08
Baltimore	MD	0.41	0.54	0.74	0.52	0.11
Belmont	MA		0.19		0.48	
Bergen Co.	NJ		0.75	0.57	0.74	
Birmingham	AL	0.18	0.62	0.71	0.84	0.66
Boston	MA	0.25	0.43	0.48	0.50	0.25
Bronx	NY	0.51	0.79	0.82	0.91	0.40
Brookline	MA	0.23	0.34	0.41	0.50	0.26
Brooklyn	NY	0.31	0.59	0.68	0.66	0.36
Buffalo	NY	0.42	0.59	0.69	0.86	0.44
Cambridge	MA	0.09	0.18	0.24	0.32	0.23
Camden	NJ	0.99	0.85	0.92	0.96	-0.03
Chicago	IL	0.11	0.53	0.63	0.65	0.54
Cleveland	OH	0.30	0.47	0.60	0.76	0.46
Columbus	OH	0.25	0.52	0.55	0.68	0.43
Dallas	TX	0.16	0.51	0.66	0.59	0.43
Dayton	OH	0.16	0.65	0.70	0.78	0.62
Dedham	MA			0.37	0.81	
Denver	CO	0.09	0.17	0.31	0.60	0.51
Des Moines	IA	0.61	0.59	0.68	0.74	0.13
Detroit	MI	0.26	0.40	0.64	0.77	0.51
Duluth	MN	0.28	0.29	0.38	0.58	0.29
East St. Louis	IL	0.59	0.60	0.73	0.84	0.25
Essex Co.	NJ	0.54	0.75	0.82	0.85	0.31
Flint	MI	0.68	0.77	0.80	0.76	0.09
Greater Kansas City	MO	0.02	0.25	0.52	0.76	0.74
Hartford	CT	0.34	0.60	0.71	0.82	0.48
Houston	TX	0.25	0.62	0.76	0.52	0.27
Hudson Co.	NJ		0.61	0.71	0.64	

City	State	Overall SVI (A)	Overall SVI (B)	Overall SVI (C)	Overall SVI (D)	D-A (Overall SVI)
Indianapolis	IN	0.35	0.48	0.70	0.65	0.31
Los Angeles	CA	0.28	0.43	0.61	0.68	0.41
Louisville	KY	0.13	0.34	0.52	0.77	0.64
Lower Westchester Co.	NY	0.59	0.60	0.62	0.72	0.14
Macon	GA	0.57	0.62	0.64	0.79	0.22
Manhattan	NY	0.25	0.52	0.50	0.51	0.26
Memphis	TN	0.40	0.66	0.73	0.84	0.44
Milton	MA	0.57	0.58	0.36		
Milwaukee Co.	WI	0.34	0.42	0.65	0.62	0.29
Minneapolis	MN	0.18	0.33	0.47	0.58	0.40
Nashville	TN	0.20	0.28	0.37	0.62	0.42
New Britain	CT		0.42	0.52		
New Haven	CT	0.61	0.40	0.66	0.84	0.23
New Orleans	LA	0.26	0.33	0.47	0.65	0.39
Newton	MA		0.20			
Oakland	CA	0.08	0.41	0.51	0.65	0.57
Oklahoma City	OK	0.32	0.64	0.68	0.78	0.46
Pawtucket & Central Falls	RI		0.85			
Philadelphia	PA	0.57	0.66	0.66	0.70	0.13
Pittsburgh	PA	0.18	0.30	0.48	0.56	0.38
Portland	OR	0.14	0.20	0.39	0.33	0.19
Providence	RI	0.50	0.66	0.71	0.64	0.14
Queens	NY	0.60	0.46	0.60	0.66	0.06
Richmond	VA	0.29	0.32	0.55	0.60	0.31
Rochester	NY	0.42	0.53	0.68	0.81	0.38
San Francisco	CA	0.25	0.35	0.34	0.46	0.21
Savannah	GA	0.54	0.58	0.80	0.70	0.16
Seattle	WA	0.17	0.24	0.24	0.36	0.19
Somerville	MA			0.22		
St. Louis	MO	0.26	0.46	0.53	0.61	0.35
St. Paul	MN	0.27	0.39	0.67	0.62	0.34
Staten Island	NY	0.34	0.37	0.46	0.48	0.14
Syracuse	NY	0.45	0.53	0.71	0.87	0.42
Toledo	OH	0.49	0.62	0.68	0.86	0.36
Trenton	NJ	0.79	0.76	0.85	0.94	0.15
Union Co.	NJ	0.50	0.64	0.79	0.84	0.33
Winthrop	MA					

Table A2: Average socioeconomic SVI scores for U.S. urban areas or cities grouped by HOLC grades among all HOLC neighborhood polygons that overlapped 1940 U.S. Census tracts. D-A is the difference between SVI for HOLC grades A and D neighborhoods within an urban area. An urban area with a white cell without SVI score does not have SVI score for that particular HOLC grade. Darker green colors indicate lower average SVI scores while darker red colors indicate higher average SVI scores.

City	State	Socioeconomic SVI (A)	Socioeconomic SVI (B)	Socioeconomic SVI (C)	Socioeconomic SVI (D)	D-A (Socioeconomic SVI)
Akron	OH	0.45	0.59	0.72	0.79	0.34
Arlington	MA			0.08		
Atlanta	GA	0.05	0.26	0.39	0.57	0.51
Atlantic City	NJ		0.74	0.92	0.94	
Augusta	GA	0.38	0.49	0.68	0.78	0.41
Austin	TX	0.27	0.31	0.27	0.29	0.02
Baltimore	MD	0.41	0.56	0.80	0.55	0.14
Belmont	MA		0.07		0.29	
Bergen Co.	NJ		0.60	0.51	0.69	
Birmingham	AL	0.15	0.62	0.75	0.91	0.76
Boston	MA	0.11	0.38	0.42	0.46	0.34
Bronx	NY	0.31	0.66	0.73	0.87	0.56
Brookline	MA	0.15	0.22	0.40	0.18	0.03
Brooklyn	NY	0.17	0.48	0.63	0.62	0.45
Buffalo	NY	0.48	0.64	0.73	0.87	0.39
Cambridge	MA	0.03	0.10	0.17	0.28	0.25
Camden	NJ	0.97	0.84	0.92	0.94	-0.03
Chicago	IL	0.09	0.50	0.63	0.70	0.61
Cleveland	OH	0.30	0.52	0.66	0.86	0.55
Columbus	OH	0.30	0.58	0.64	0.76	0.47
Dallas	TX	0.13	0.56	0.65	0.61	0.48
Dayton	OH	0.18	0.76	0.81	0.87	0.69
Dedham	MA			0.28	0.57	
Denver	CO	0.06	0.15	0.31	0.57	0.51
Des Moines	IA	0.61	0.53	0.64	0.69	0.08
Detroit	MI	0.31	0.48	0.72	0.84	0.53
Duluth	MN	0.26	0.38	0.38	0.52	0.26
East St. Louis	IL	0.71	0.73	0.87	0.90	0.19
Essex Co.	NJ	0.56	0.74	0.81	0.84	0.28
Flint	MI	0.74	0.85	0.88	0.84	0.10
Greater Kansas City	MO	0.05	0.31	0.57	0.80	0.76
Hartford	CT	0.29	0.54	0.66	0.75	0.46
Houston	TX	0.24	0.61	0.75	0.51	0.28
Hudson Co.	NJ		0.52	0.60	0.55	
Indianapolis	IN	0.39	0.56	0.76	0.73	0.34
Los Angeles	CA	0.22	0.38	0.56	0.63	0.41
Louisville	KY	0.16	0.39	0.56	0.81	0.65
Lower Westchester Co.	NY	0.41	0.48	0.53	0.67	0.25

City	State	Socioeconomic SVI (A)	Socioeconomic SVI (B)	Socioeconomic SVI (C)	Socioeconomic SVI (D)	D-A (Socioeconomic SVI)
Macon	GA	0.59	0.56	0.69	0.84	0.26
Manhattan	NY	0.11	0.40	0.39	0.37	0.26
Memphis	TN	0.46	0.73	0.80	0.91	0.45
Milton	MA	0.45	0.49	0.31		
Milwaukee Co.	WI	0.38	0.48	0.69	0.65	0.27
Minneapolis	MN	0.18	0.33	0.46	0.56	0.38
Nashville	TN	0.06	0.34	0.44	0.64	0.58
New Britain	CT		0.43	0.48		
New Haven	CT	0.44	0.38	0.67	0.82	0.38
New Orleans	LA	0.34	0.47	0.56	0.75	0.40
Newton	MA		0.14			
Oakland	CA	0.05	0.30	0.42	0.58	0.53
Oklahoma City	OK	0.38	0.71	0.76	0.83	0.45
Pawtucket & Central Falls	RI		0.76			
Philadelphia	PA	0.54	0.64	0.70	0.73	0.19
Pittsburgh	PA	0.16	0.31	0.52	0.59	0.43
Portland	OR	0.11	0.20	0.37	0.29	0.18
Providence	RI	0.48	0.72	0.73	0.67	0.19
Queens	NY	0.26	0.33	0.55	0.59	0.33
Richmond	VA	0.29	0.35	0.64	0.70	0.41
Rochester	NY	0.34	0.58	0.73	0.84	0.50
San Francisco	CA	0.13	0.22	0.24	0.33	0.21
Savannah	GA	0.57	0.67	0.89	0.76	0.19
Seattle	WA	0.07	0.18	0.19	0.26	0.19
Somerville	MA			0.15		
St. Louis	MO	0.28	0.49	0.57	0.63	0.35
St. Paul	MN	0.25	0.34	0.60	0.52	0.28
Staten Island	NY	0.20	0.33	0.40	0.45	0.25
Syracuse	NY	0.36	0.54	0.73	0.92	0.56
Toledo	OH	0.63	0.71	0.79	0.93	0.30
Trenton	NJ	0.76	0.87	0.88	0.95	0.20
Union Co.	NJ	0.51	0.61	0.71	0.84	0.33
Winthrop	MA			1.00		

Table A3: Average minority status/language SVI scores for U.S. urban areas or cities grouped by HOLC grades among all HOLC neighborhood polygons that overlapped 1940 U.S. Census tracts. D-A is the difference between SVI for HOLC grades A and D neighborhoods within an urban area. An urban area with a white cell without SVI score does not have SVI score for that particular HOLC grade. Darker green colors indicate lower average SVI scores while darker red colors indicate higher average SVI scores.

City	State	Minority status/ language SVI (A)	Minority status/ language SVI (B)	Minority status/ language SVI (C)	Minority status/ language SVI (D)	D-A (Minority status/ language SVI)
Akron	OH	0.35	0.33	0.42	0.49	0.14
Arlington	MA			0.49		
Atlanta	GA	0.31	0.46	0.46	0.54	0.22
Atlantic City	NJ		0.88	0.88	0.89	
Augusta	GA	0.38	0.40	0.45	0.47	0.09
Austin	TX	0.43	0.44	0.55	0.44	0.00
Baltimore	MD	0.48	0.52	0.66	0.57	0.09
Belmont	MA		0.53		0.67	
Bergen Co.	NJ		0.93	0.87	0.94	
Birmingham	AL	0.22	0.54	0.57	0.64	0.42
Boston	MA	0.54	0.65	0.66	0.69	0.14
Bronx	NY	0.64	0.84	0.87	0.92	0.28
Brookline	MA	0.51	0.54	0.65	0.74	0.23
Brooklyn	NY	0.56	0.71	0.77	0.77	0.21
Buffalo	NY	0.52	0.59	0.58	0.70	0.17
Cambridge	MA	0.10	0.25	0.40	0.63	0.53
Camden	NJ	0.92	0.87	0.94	0.94	0.02
Chicago	IL	0.48	0.63	0.72	0.69	0.21
Cleveland	OH	0.40	0.48	0.51	0.60	0.19
Columbus	OH	0.33	0.46	0.43	0.50	0.16
Dallas	TX	0.43	0.77	0.82	0.73	0.30
Dayton	OH	0.17	0.48	0.47	0.53	0.36
Dedham	MA			0.64	0.81	
Denver	CO	0.28	0.34	0.47	0.75	0.46
Des Moines	IA	0.52	0.54	0.64	0.70	0.18
Detroit	MI	0.34	0.37	0.50	0.57	0.22
Duluth	MN	0.25	0.18	0.17	0.22	-0.03
East St. Louis	IL	0.47	0.49	0.53	0.59	0.12
Essex Co.	NJ	0.72	0.83	0.89	0.90	0.18
Flint	MI	0.44	0.48	0.46	0.37	-0.07
Greater Kansas City	MO	0.15	0.30	0.50	0.72	0.57
Hartford	CT	0.49	0.67	0.81	0.87	0.38
Houston	TX	0.58	0.82	0.88	0.77	0.19
Hudson Co.	NJ		0.85	0.88	0.84	
Indianapolis	IN	0.40	0.43	0.60	0.55	0.16
Los Angeles	CA	0.63	0.71	0.81	0.87	0.23
Louisville	KY	0.19	0.29	0.38	0.46	0.27
Lower Westchester Co.	NY	0.74	0.77	0.74	0.83	0.10
Macon	GA	0.33	0.39	0.43	0.48	0.15

City	**State**	**Minority status/ language SVI (A)**	**Minority status/ language SVI (B)**	**Minority status/ language SVI (C)**	**Minority status/ language SVI (D)**	**D-A (Minority status/ language SVI)**
Manhattan	NY	0.43	0.64	0.60	0.67	0.23
Memphis	TN	0.38	0.63	0.55	0.61	0.23
Milton	MA	0.73	0.78	0.63		
Milwaukee Co.	WI	0.40	0.49	0.60	0.61	0.21
Minneapolis	MN	0.37	0.45	0.55	0.68	0.31
Nashville	TN	0.28	0.37	0.42	0.54	0.26
New Britain	CT		0.59	0.65		
New Haven	CT	0.80	0.53	0.73	0.82	0.03
New Orleans	LA	0.37	0.41	0.50	0.57	0.20
Newton	MA		0.55			
Oakland	CA	0.49	0.70	0.77	0.80	0.32
Oklahoma City	OK	0.51	0.79	0.71	0.79	0.27
Pawtucket & Central Falls	RI		0.88			
Philadelphia	PA	0.65	0.68	0.64	0.64	0.00
Pittsburgh	PA	0.28	0.30	0.36	0.41	0.13
Portland	OR	0.32	0.38	0.51	0.44	0.12
Providence	RI	0.56	0.79	0.80	0.69	0.13
Queens	NY	0.76	0.75	0.84	0.78	0.02
Richmond	VA	0.26	0.33	0.51	0.55	0.29
Rochester	NY	0.48	0.58	0.66	0.69	0.22
San Francisco	CA	0.68	0.77	0.67	0.77	0.09
Savannah	GA	0.46	0.49	0.61	0.52	0.06
Seattle	WA	0.41	0.47	0.45	0.54	0.14
Somerville	MA			0.37		
St. Louis	MO	0.37	0.43	0.46	0.51	0.15
St. Paul	MN	0.44	0.53	0.71	0.62	0.17
Staten Island	NY	0.54	0.57	0.60	0.64	0.10
Syracuse	NY	0.54	0.53	0.57	0.74	0.20
Toledo	OH	0.48	0.42	0.45	0.60	0.12
Trenton	NJ	0.70	0.89	0.84	0.89	0.19
Union Co.	NJ	0.85	0.89	0.93	0.94	0.09
Winthrop	MA			0.86		

Table A4: Average housing type/transportation SVI scores for U.S. urban areas or cities grouped by HOLC grades among all HOLC neighborhood polygons that overlapped 1940 U.S. Census tracts. D-A is the difference between SVI for HOLC grades A and D neighborhoods within an urban area. An urban area with a white cell without SVI score does not have SVI score for that particular HOLC grade. Darker green colors indicate lower average SVI scores while darker red colors indicate higher average SVI scores.

City	State	Housing/ Transportation SVI (A)	Housing/ Transportation SVI (B)	Housing/ Transportation SVI (C)	Housing/ Transportation SVI (D)	D- A (Housing/ Transportation SVI)
Akron	OH	0.36	0.40	0.50	0.61	0.25
Arlington	MA			0.72		
Atlanta	GA	0.46	0.51	0.49	0.59	0.13
Atlantic City	NJ		0.71	0.73	0.84	
Augusta	GA	0.35	0.38	0.48	0.74	0.39
Austin	TX	0.43	0.71	0.86	0.65	0.22
Baltimore	MD	0.49	0.51	0.54	0.64	0.15
Belmont	MA		0.36		0.90	
Bergen Co.	NJ		0.86	0.53	0.76	
Birmingham	AL	0.50	0.71	0.65	0.64	0.13
Boston	MA	0.44	0.56	0.65	0.70	0.26
Bronx	NY	0.82	0.87	0.78	0.85	0.02
Brookline	MA	0.48	0.69	0.78	0.81	0.33
Brooklyn	NY	0.58	0.72	0.75	0.73	0.16
Buffalo	NY	0.53	0.55	0.50	0.67	0.14
Cambridge	MA	0.32	0.56	0.72	0.67	0.35
Camden	NJ	0.86	0.56	0.65	0.81	-0.05
Chicago	IL	0.21	0.53	0.55	0.54	0.33
Cleveland	OH	0.32	0.39	0.43	0.50	0.17
Columbus	OH	0.20	0.48	0.50	0.58	0.38
Dallas	TX	0.28	0.43	0.60	0.59	0.32
Dayton	OH	0.11	0.50	0.45	0.60	0.49
Dedham	MA			0.48	0.84	
Denver	CO	0.28	0.32	0.59	0.68	0.40
Des Moines	IA	0.57	0.65	0.63	0.71	0.15
Detroit	MI	0.17	0.29	0.45	0.59	0.42
Duluth	MN	0.38	0.42	0.56	0.78	0.40
East St. Louis	IL	0.40	0.34	0.38	0.67	0.27
Essex Co.	NJ	0.44	0.59	0.65	0.64	0.20
Flint	MI	0.38	0.53	0.57	0.65	0.27
Greater Kansas City	MO	0.08	0.29	0.50	0.57	0.49
Hartford	CT	0.43	0.57	0.69	0.82	0.40
Houston	TX	0.52	0.56	0.66	0.57	0.05
Hudson Co.	NJ		0.70	0.74	0.72	
Indianapolis	IN	0.28	0.40	0.53	0.56	0.27
Los Angeles	CA	0.34	0.50	0.65	0.70	0.37
Louisville	KY	0.30	0.43	0.58	0.78	0.48
Lower Westchester Co.	NY	0.74	0.67	0.67	0.68	-0.06

City	State	Housing/ Transportation SVI (A)	Housing/ Transportation SVI (B)	Housing/ Transportation SVI (C)	Housing/ Transportation SVI (D)	D- A (Housing/ Transportation SVI)
Macon	GA	0.39	0.56	0.57	0.68	0.29
Manhattan	NY	0.66	0.83	0.82	0.87	0.21
Memphis	TN	0.50	0.44	0.57	0.62	0.12
Milton	MA	0.58	0.55	0.33		
Milwaukee Co.	WI	0.42	0.40	0.56	0.58	0.16
Minneapolis	MN	0.32	0.50	0.62	0.69	0.37
Nashville	TN	0.79	0.61	0.58	0.72	-0.07
New Britain	CT		0.37	0.46		
New Haven	CT	0.82	0.48	0.65	0.76	-0.06
New Orleans	LA	0.19	0.32	0.45	0.52	0.33
Newton	MA		0.57			
Oakland	CA	0.13	0.50	0.67	0.73	0.59
Oklahoma City	OK	0.41	0.48	0.50	0.60	0.19
Pawtucket & Central Falls	RI		0.68			
Philadelphia	PA	0.58	0.54	0.52	0.62	0.04
Pittsburgh	PA	0.39	0.42	0.49	0.49	0.10
Portland	OR	0.35	0.40	0.63	0.71	0.36
Providence	RI	0.59	0.55	0.62	0.70	0.11
Queens	NY	0.93	0.59	0.59	0.66	-0.27
Richmond	VA	0.51	0.52	0.46	0.56	0.05
Rochester	NY	0.56	0.48	0.53	0.69	0.13
San Francisco	CA	0.42	0.55	0.66	0.70	0.27
Savannah	GA	0.42	0.51	0.73	0.76	0.34
Seattle	WA	0.44	0.50	0.57	0.68	0.24
Somerville	MA			0.63		
St. Louis	MO	0.36	0.46	0.47	0.59	0.23
St. Paul	MN	0.50	0.58	0.76	0.70	0.20
Staten Island	NY	0.61	0.47	0.57	0.52	-0.09
Syracuse	NY	0.59	0.51	0.57	0.77	0.19
Toledo	OH	0.37	0.45	0.43	0.56	0.19
Trenton	NJ	0.71	0.42	0.60	0.70	-0.01
Union Co.	NJ	0.37	0.55	0.69	0.68	0.31
Winthrop	MA			.		

Table A5: Average household composition/disability SVI scores for U.S. urban areas or cities grouped by HOLC grades among all HOLC neighborhood polygons that overlapped 1940 U.S. Census tracts. D-A is the difference between SVI for HOLC grades A and D neighborhoods within an urban area. An urban area with a white cell without SVI score does not have SVI score for that particular HOLC grade. Darker green colors indicate lower average SVI scores while darker red colors indicate higher average SVI scores.

City	State	Household composition SVI (A)	Household composition SVI (B)	Household composition SVI (C)	Household composition SVI (D)	D-A (Household composition SVI)
Akron	OH	0.53	0.57	0.60	0.68	0.15
Arlington	MA			0.08		
Atlanta	GA	0.22	0.28	0.32	0.43	0.21
Atlantic City	NJ		0.66	0.79	0.91	
Augusta	GA	0.49	0.54	0.60	0.67	0.17
Austin	TX	0.06	0.08	0.17	0.04	-0.02
Baltimore	MD	0.34	0.50	0.67	0.37	0.03
Belmont	MA		0.22		0.08	
Bergen Co.	NJ		0.25	0.29	0.21	
Birmingham	AL	0.13	0.49	0.62	0.71	0.58
Boston	MA	0.27	0.30	0.30	0.24	-0.03
Bronx	NY	0.25	0.55	0.66	0.78	0.54
Brookline	MA	0.13	0.23	0.09	0.33	0.20
Brooklyn	NY	0.19	0.33	0.32	0.37	0.18
Buffalo	NY	0.28	0.46	0.75	0.87	0.59
Cambridge	MA	0.35	0.18	0.06	0.07	-0.28
Camden	NJ	0.95	0.84	0.81	0.85	-0.10
Chicago	IL	0.25	0.42	0.47	0.50	0.25
Cleveland	OH	0.40	0.52	0.65	0.73	0.33
Columbus	OH	0.30	0.49	0.50	0.63	0.33
Dallas	TX	0.22	0.32	0.37	0.34	0.12
Dayton	OH	0.55	0.66	0.80	0.76	0.22
Dedham	MA			0.26	0.75	
Denver	CO	0.16	0.16	0.14	0.33	0.17
Des Moines	IA	0.66	0.51	0.68	0.66	0.00
Detroit	MI	0.47	0.54	0.67	0.73	0.26
Duluth	MN	0.50	0.34	0.48	0.59	0.09
East St. Louis	IL	0.62	0.67	0.76	0.82	0.21
Essex Co.	NJ	0.40	0.55	0.65	0.63	0.23
Flint	MI	0.89	0.81	0.83	0.73	-0.16
Greater Kansas City	MO	0.12	0.27	0.45	0.66	0.55
Hartford	CT	0.34	0.53	0.51	0.66	0.32
Houston	TX	0.07	0.42	0.52	0.33	0.26
Hudson Co.	NJ		0.25	0.38	0.32	
Indianapolis	IN	0.47	0.49	0.64	0.57	0.10
Los Angeles	CA	0.26	0.26	0.31	0.34	0.08
Louisville	KY	0.24	0.39	0.47	0.63	0.38
Lower Westchester Co.	NY	0.37	0.36	0.42	0.47	0.10

City	State	Household composition SVI (A)	Household composition SVI (B)	Household composition SVI (C)	Household composition SVI (D)	D-A (Household composition SVI)
Macon	GA	0.85	0.84	0.62	0.67	-0.18
Manhattan	NY	0.18	0.21	0.20	0.20	0.03
Memphis	TN	0.31	0.58	0.67	0.82	0.51
Milton	MA	0.51	0.56	0.37		
Milwaukee Co.	WI	0.35	0.39	0.59	0.53	0.18
Minneapolis	MN	0.17	0.24	0.27	0.34	0.17
Nashville	TN	0.06	0.04	0.23	0.43	0.37
New Britain	CT		0.44	0.52		
New Haven	CT	0.21	0.41	0.48	0.62	0.42
New Orleans	LA	0.33	0.28	0.35	0.53	0.20
Newton	MA		0.05			
Oakland	CA	0.20	0.32	0.24	0.33	0.14
Oklahoma City	OK	0.14	0.41	0.52	0.58	0.44
Pawtucket & Central Falls	RI		0.79			
Philadelphia	PA	0.41	0.62	0.59	0.57	0.16
Pittsburgh	PA	0.23	0.34	0.55	0.66	0.42
Portland	OR	0.14	0.13	0.16	0.09	-0.05
Providence	RI	0.39	0.50	0.52	0.35	-0.04
Queens	NY	0.29	0.23	0.29	0.40	0.11
Richmond	VA	0.23	0.19	0.48	0.44	0.20
Rochester	NY	0.43	0.45	0.61	0.65	0.22
San Francisco	CA	0.18	0.14	0.10	0.17	-0.01
Savannah	GA	0.61	0.48	0.57	0.44	-0.17
Seattle	WA	0.14	0.12	0.10	0.17	0.03
Somerville	MA			0.05		
St. Louis	MO	0.25	0.48	0.54	0.50	0.25
St. Paul	MN	0.19	0.28	0.47	0.52	0.32
Staten Island	NY	0.20	0.28	0.29	0.34	0.14
Syracuse	NY	0.36	0.51	0.72	0.67	0.31
Toledo	OH	0.48	0.73	0.79	0.86	0.38
Trenton	NJ	0.62	0.48	0.64	0.85	0.23
Union Co.	NJ	0.32	0.36	0.50	0.50	0.17
Winthrop	MA			0.05		