

Does Racial Residential Segregation Influence Smoking Behaviors?
The Multi-Ethnic Study of Atherosclerosis

Benjamin Bryer

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Committee:
Anjum Hajat
Clarence Spigner
Mandy Fretts

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University of Washington

Abstract

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Benjamin Bryer

Chair of the Supervisory Committee:
Anjum Hajat
Department of Epidemiology

Background and Objectives:

Tobacco cigarette smoking remains the leading cause of preventable morbidity and mortality in the United States. Racial residential segregation (RRS) in American cities may be contributing to high rates of smoking in some communities. Yet, limited research exists investigating the association between segregation and smoking behaviors. The aim of this study was to examine the negative effects of RRS on smoking status and smoking intensity. We also investigated whether the association of segregation and smoking was modified by race and ethnicity. While past RRS research mainly focused on the smoking disparities between White and Black individuals, this study included the effects of RRS on Hispanic and Chinese individuals to better understand how neighborhood segregation may influence individual smoking behaviors among a diverse study sample.

Methods:

We used longitudinal data from the Multi-Ethnic Study of Atherosclerosis (MESA) with repeated observations over five study visits between 2000 and 2012. Segregation was operationalized with Divergence Index z-score tertile categories (Low, Med, High), calculated at the census-tract level. Our primary outcome was smoking status (Former/Never vs. Current), and our secondary outcome was smoking intensity (<10 vs ≥ 10 cigarettes per day). We used generalized estimating equations (GEE) to account for the longitudinal nature of the data (multiple

observations per person). Models were adjusted for key covariates (age, gender, race and ethnicity, birthplace, and field center), and stratified by race and ethnicity.

Results:

Our final sample consisted of 28,912 observations from 6,710 individuals. At baseline, individuals who reported being a current cigarette smoker were more likely to be male gender, Black race, born in the U.S. and have a younger age than the overall study population. While those living in areas categorized as “Low RRS” had a lower prevalence of current smokers than higher RRS categories, current smokers living in low segregation had a higher median smoking intensity. In our GEE models, we found that participants living in high segregation had 1.51 (95% CI: 1.21,1.88) times higher odds of being a current smoker compared to participants living in low segregation. Black participants living in either medium (OR: 1.92, 95% CI: 1.24,2.97) or high (OR: 1.59, 95% CI: 1.09,2.32) segregation, and Hispanic/Latinx participants living in medium segregation (OR: 1.63, 95% CI: 1.08,2.48), had statistically higher odds of reporting as a current smoker than among those living in low segregation, adjusted for key covariates. There was no significant association between smoking status and segregation for Chinese or White participants. There were also no significant adjusted ORs for smoking intensity and segregation, even when stratified by race and ethnicity.

Conclusions:

This study suggests that racial segregation may be associated with being a current smoker, though segregation may not influence smoking intensity among current smokers. Previous research has shown that even smoking a few cigarettes per day can increase the chances of developing cardiovascular disease and other smoking-related health outcomes. Our study is a crucial piece in understanding the health behaviors of segregated communities, especially among Black and Hispanic/Latinx populations.

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Background

Tobacco cigarette smoking, which causes over 480,000 deaths per year in the United States, remains the leading cause of preventable morbidity and mortality in the country (1). While the prevalence of cigarette smoking has declined by almost 9% since 2005, 12.5% of U.S. adults reported as current cigarette smokers in 2020 (2). The negative health effects of cigarette smoking are well documented. Smoking is a known risk factor for heart disease, stroke, and lung cancer, among other negative health outcomes (1). More than 16 million American adults currently live with a smoking-related condition (1). Racial disparities in smoking rates exist, as White (13.3%) and Black (14.4%) adults reported similar smoking prevalence, and Asian and Hispanic adults reported lower rates of smoking prevalence (approx. 8.0%) in 2020 (2). Yet, research has shown that non-White smokers tend to smoke fewer cigarettes per day as compared to White smokers (3,4).

Numerous studies have investigated the impacts of the social and physical environment on smoking behaviors. Adults living in neighborhoods with worse social environments, measured by physical aesthetic, safety, and social cohesion, tend to report higher smoking prevalence than those in better neighborhood social environments (5). Stress originating from psychosocial factors such as personal relationships, occupation, socioeconomic status (SES), family issues, and perceived inequality is strongly correlated with higher odds of persistent smoking over time (6). Research has shown that stress is an influential factor in the behavior of daily smokers, such as an increased smoking intensity and decreased ability to resist smoking (7). Additionally, higher perceived discrimination is associated with greater odds of unhealthy behaviors such as cigarette use and heavy alcohol consumption (8). External factors such as stress, discrimination, and neighborhood environment may be influential in an individual's likelihood to smoke cigarettes. These factors help to create the social and built environment of a neighborhood, which have immense impacts on the health of its residents (9,10). One influential element for the wellbeing of a community may be the extent to which that area is racially segregated from surrounding neighborhoods.

U.S. neighborhoods today remain extremely fractured by racial identity, and over 80% of American cities were more segregated in 2019 than they were in 1990 (11,12). Many Americans live in neighborhoods with higher proportions of their own race or ethnicity as compared to the national average. As of the 2010 census, 72% of Americans identified as White alone, 13% as Black alone, 5% as Asian alone, and 16% as Hispanic/Latinx (13). Between 2014-2018, the average White resident lived in a neighborhood that was 71% White, the average Black resident lived in a neighborhood that was 45% Black, and the average Hispanic/Latinx resident lived in a neighborhood that was 47% Hispanic/Latinx (14). With the residential separation of racial groups comes the unequal distribution of resources that influences one's socioeconomic status, and quality of life. Segregated communities of color have about three times the neighborhood poverty rates as segregated White areas (11,12). Low-income individuals are more likely to live in low-income neighborhoods, and concentrated poverty is much more prevalent among non-White populations (15).

Racial residential segregation (RRS) has been argued to be a fundamental cause of racial disparities in health outcomes (16). The systematic separation of racialized populations, especially the segregation of Black Americans, through economic programs and policies such as mortgage redlining, and a lack of educational and occupational opportunities, has led to worse health outcomes among segregated communities (16). Built environmental hazards, such as neighborhood segregation, may manifest itself in the body through psychosocial stress, which in turn may lead to unhealthy behaviors and poor health outcomes (17). Additionally, RRS may affect individual health outcomes through limited socioeconomic opportunities, unhealthy neighborhood environments, modified social capital, and stressful stimuli (18). Many adverse health outcomes between racially segregated communities are not equally distributed. Black individuals living in racially segregated communities have been shown to have a higher proportion of cancer mortality (19), incident hypertension (20), low birth weight (21), and worse childhood health (22) than low-segregation White communities. Segregated Black communities may be less likely to have access to neighborhood health services, such as hospitals, pharmacies, and other medical facilities (23). Racially segregated and impoverished neighborhoods have also been shown to have a higher density of tobacco retailers, indicating the disparity in the availability of unhealthy products between low and highly segregated communities (24,25). Black children living in high segregation have been shown to be more likely to access tobacco products and develop smoking habits as compared to those not living in high segregation (26–28).

Research suggests that RRS leads to poor health outcomes and worse health behaviors for racialized and minoritized groups. In highly segregated non-Hispanic Black communities, there may be an increased likelihood for an individual to engage in injection drug use (29), alcohol consumption and binge drinking (30,31), and risky sexual behaviors (32). While racial residential segregation has been shown to negatively affect the health outcomes and behaviors of Black and African American individuals in the U.S., research does not support a similar relationship among White individuals living in various levels of segregation. In recent studies, RRS has not been shown to affect lifetime survival probability (33), nor breast cancer survival (34) nor colorectal cancer mortality (35), among other health conditions for White individuals living in varying levels of segregation.

Psychosocial stress may manifest itself as a cause of smoking behaviors (6), and as an effect of racial residential segregation (18). Yet, there is a lack of literature on the association of RRS on cigarette smoking behavior. A study on health behaviors and young adult health among Black Americans found that Black individuals who had always lived in highly segregated areas were more likely to be current smokers than those not living in high segregation (30). Yet, Black individuals who moved from low segregation to high segregation during childhood were more likely to smoke more than 10 cigarettes a day than those who had always lived in high segregation (30). One study on pregnant urban African American women found that both low and high levels of segregation were associated with higher odds of smoking during pregnancy as compared to individuals living in moderately segregated environments (36). Another study found no differences in White-Black smoking disparities between a racially integrated example

and a national health survey (37). Landrine and Klonoff investigated the association between racial residential segregation and smoking among Black individuals using self-reported segregation measures (26). They found that the prevalence of smoking was correlated with high-segregation responses among participants, with an even stronger correlation for reported neighborhood segregation during one's childhood. Yet, previous literature has not investigated the longitudinal association of segregation on both smoking status and smoking intensity, especially within a multiracial sample.

The aim of this study was to build on the foundation of research on the negative effects of RRS on health behaviors, particularly smoking status and smoking intensity. While past RRS research focused on the smoking disparities between White and Black individuals, this study included the effects of RRS on Hispanic and Chinese individuals to better understand how neighborhood segregation may influence individual smoking behaviors among a diverse study sample. This study used a longitudinal study design with repeated observational measures to assess the relationship of RRS and smoking behaviors over time.

Methods

Study Design

Study data were from the Multi-Ethnic Study of Atherosclerosis (MESA) (38). MESA, a longitudinal cohort study, was initiated in the year 2000 and baseline data were collected over a two-year period. The study aimed to investigate the burden of subclinical cardiovascular disease (CVD) over-time among enrolled participants from diverse populations. The MESA study was approved by an Institutional Review Board at each study location, and each participant provided written informed consent. This thesis project was determined to not involve "human subjects" as defined by federal regulations and did not require exempt status or IRB review.

At baseline (2000-2002), MESA researchers recruited 6,814 adults, between the ages of 45-84 and free of clinical cardiovascular disease. Male and female participants were recruited from six urban U.S. field centers: Los Angeles, CA, Manhattan and Bronx, NY, St. Paul, MN, Chicago, IL, Baltimore, MD, and Forsyth County (Winston-Salem), NC. Participants were restricted to four racial and ethnic categories, specifically those who self-identified as White, African American, Hispanic/Latinx, or Chinese. Not all study sites recruited participants from each racial or ethnic group. While White individuals were recruited at all six field centers, the study did not include Black participants from Minnesota, and Hispanic/Latinx participants from Illinois, North Carolina, and Maryland. Chinese American participants were only recruited from Illinois and California.

In addition to baseline data, we used data from four follow-up visits: Exam 2 (2002–2004), Exam 3 (2004–2005), Exam 4 (2005–2007), Exam 5 (2010–2012). Examinations consisted of health history questionnaires, blood testing, vital signs, and cardiovascular-related tests such as carotid ultrasonography, cardiac imaging, and chest computed tomography, among others. Only

data collected from participant questionnaires on self-reported health history, behaviors, and an assortment of quality-of-life measures were used for our study.

Racial Residential Segregation

The primary exposure of our study was racial residential segregation (RRS). We operationalized RRS using the Divergence Index, which was developed by Dr. Elizabeth Roberto in 2016 (39). The index measures how much the racial composition of a given geographical area “diverges” from the racial compositions of its surrounding region. In other words, the Divergence Index calculates how different the racial make-up of an area is compared to its surrounding areas. Unlike other measures of segregation, the Divergence index presents a single, multiracial composite value for all individuals living within a shared census tract. The Divergence index is decomposable, meaning that the level of segregation in an area is evaluated at a granular level occurring within and between groups (39). In effect, the Divergence index captures a more nuanced picture of segregation and inequality of racial distribution rather than just relative diversity in an area (40).

As the Divergence Index is a relatively new measure of racial residential segregation, there have only been a few published studies that have used the construct (40–43). We chose to use the Divergence Index because of its advantages as discussed above, as well as the desire to use a novel and underutilized measure as part of our research.

In our study, Divergence was calculated by adding up the proportion of each racial group in the census tract of residence for each MESA participant, multiplied by the log of the relation between the census tract proportion and the proportion in the Core-based statistical area (CBSA) (the comparison or surrounding area) (39). Baseline address for MESA participants was geocoded to their corresponding census tract and CBSA. If a participant left their recruitment site, they were lost to follow-up. We calculated the Divergence Index score using the participant’s residential address at their baseline visit (between 2000-2002) of MESA data collection. We used standardized z-scores to facilitate the interpretation of the extent of segregation between racial groups in each geographic area. A z-score of zero represented the mean segregation value, with positive values of the z-score indicating a more segregated census tract, and negative values representing lower levels of segregation.

Our primary measure of RRS was the Divergence Index z-score at the spatial census tract level using data from the 2000 U.S. Census. Spatial census-tract level population estimates were created by summing the population of each racial group in a given census tract with that of adjacent tracts multiplied by the inverse weights of the distance in miles (or 1 if less than 1 mile) between neighbors. These counts were rounded to integer values, counts of <3 individuals were suppressed, and the total population was calculated as the sum of each racial group’s population.

To aid with interpretation, we created three hierarchical categories for spatial Divergence based on the 33rd and 66th percentiles in the distributions. Values in the bottom tertile were classified

as “Low RRS,” those in the middle tertile were classified as “Med RRS,” and those in the highest tertile were classified as “High RRS.”

Smoking Variables

The primary outcome of interest was individual tobacco cigarette smoking status. A person was considered a “never” smoker if they responded “no” to the question: “Have you smoked at least 100 cigarettes in your lifetime?” Participants were characterized as “former” smokers if they had smoked at least 100 cigarettes in their lifetime, but answered “no” to the question: “Have you smoked cigarettes in the last 30 days?” Current smokers were those who had smoked 100 cigarettes in their lifetime and had smoked in the past month. Due to the immediate health benefits of smoking cessation (44), we were only concerned with reporting as a current smoker at each exam.

Smoking status was categorized as “Never, Former, or Current” in the descriptive tables, and as “Never/Former vs. Current” in the analytic models. All missing observations for smoking status were excluded from the data.

Our secondary outcome, tobacco cigarette smoking intensity for current smokers, was assessed by the question: “On average, how many cigarettes a day do/did you smoke?” Values for participants categorized as former or never smokers were recoded as missing data. Current smokers who reported zero cigarettes per day were recoded as missing values for smoking intensity. Based on the distribution of the data, the upper limit of smoking intensity was set to 60 cigarettes per day (3 packs). There were six individuals who had a single observation at or above the smoking intensity threshold. Within-person imputation was calculated for all extreme smoking intensity values as the average of a participant’s reported cigarettes per day in other exams. If a value of more than 60 cigarettes per day was the only cigarettes per day value for a participant, it was reclassified as missing. If a participant had only one other exam with a reported value for cigarettes per day, the extreme value was reassigned to the value of the participants’ one other reported smoking intensity.

Smoking intensity was classified as a continuous variable in our descriptive analyses. In our analytical models, we reclassified smoking intensity at a cut-off of a half-pack of cigarettes (“<10 cigarettes per day vs. ≥10 cigarettes per day”), based on previous literature (45).

Previous research has found the number of cigarettes smoked per day among current smokers to be a better predictor of cardiovascular outcomes than pack-years or current smoking status (46). Since the outcome of interest in this study was a health behavior (smoking) and not a health outcome (such as cardiovascular disease), we interpreted smoking behaviors as a proxy for the adverse health effects that smoking is known to cause.

Key Covariates

One major individual level time-invariant covariate of the study was self-identified race and ethnicity. Race was ascertained by the screening question: “Which of the following describes you? (You may choose more than one group),” with the options of African American or Black, Asian, Caucasian or White, Native Hawaiian or other Pacific Islander, American Indian or Alaska Native, or “Did not identify.” Those who identified as Asian were able to choose between Chinese, Filipino, Japanese, Korean, Vietnamese, and Asian Indian. Those who identified as Native Hawaiian or Pacific Islander were able to indicate as being Guamanian or Chamorro, Samoan, Micronesia, or Tahitian. Ethnicity was gathered by the screening question: “Are you Spanish/Hispanic/Latino?” If they indicated “Yes,” participants were able to select Mexican or Chicano or Mexican-American, Dominican, Puerto Rican, Cuban or fill in a blank. Participants were only invited to participate if they identified as Caucasian or White, African American or Black, Chinese, or Spanish/Hispanic/Latinx.

To account for the potential smoking-reduction effects of various state tax policies on tobacco sales and other geographic influences (47–49), we adjusted for the field center from which participants were recruited. Additionally, we adjusted for place of birth (U.S. or another country) as a proxy for potential cultural norms around smoking that may exist between those born in the United States and those born in a foreign country. Another reason to control for birthplace is to adjust for the various health advantages and disadvantages afforded to individuals living in clustered immigrant areas, often referred to as immigrant or ethnic “enclaves” (50–54). Lastly, baseline age in years and baseline gender (male or female) were included as adjustment variables. Though we were restricted by our data, we acknowledge that the gender binary does not account for the multitude of ways in which an individual may identify as their gender identity.

Individual level factors, such as personal income, educational attainment, and occupation, among others, were considered to be on the causal pathway between racial residential segregation and smoking behaviors and were therefore excluded as adjustment variables. We conceptualized education as a mediating variable rather than a confounding variable because we viewed segregation as a fundamental determinant of health and personal attainment (16). Students in high-segregation areas may go to schools that are more likely to be underfunded and they may be less likely to graduate high school or college, especially for Black students (55–58). Individuals with lower educational attainment have a higher prevalence of current smoking behaviors than individuals with higher education attainment, across racial categories (59). Therefore, we conceptualized educational attainment as being a product of racial residential segregation, as well as being influential for smoking behaviors.

Statistical Methods

Baseline descriptive statistics were stratified by smoking status (Never, Former, Current), and segregation category (Low RRS, Med RRS, High RRS). Descriptive statistics for smoking behaviors were also presented for exams 1-5. Continuous variables were presented with mean and standard deviation or median and interquartile range. Categorical variables were presented

with count (n) and percentage. Smoking behavior tables were presented with column percentages, and RRS tables were presented with row percentages to better fit the interpretation of the data. Descriptive box and bar plots were fitted to visualize relationships between key variables.

We fit generalized estimating equations (GEE) to model longitudinal data over time. This method was chosen because of its usefulness in evaluating repeated measures data and providing population-averaged interpretations. We used an exchangeable working correlation structure because the relationship between segregation and smoking behaviors was not expected to significantly change between exams over time. The GEE models were fitted with a binomial variance distribution, due to our binary smoking variables. “Low RRS” was identified as the reference category for the RRS exposure variable, and “Never/Former” was identified as the reference category for the smoking status outcome.

We ran crude models, as well as models adjusted for age, gender, race and ethnicity, field center, and birthplace, using the spatial Divergence z-score categorical variable. In addition to considering race and ethnicity as a confounder, we also examined its role as an effect modifier using stratified models adjusted for age, gender, birthplace, and field center.

Smoking intensity GEE models were fitted in the same manner as the smoking status models, with a binomial variance distribution and an exchangeable working correlation structure. Similar to smoking status, we examined potential effect modification of race and ethnicity on the association of smoking intensity and segregation, adjusted for key covariates. Current smokers who reported smoking less than 10 cigarettes per day served as the reference category in the model.

GEE models returned outputs with the log odds of the estimated regression coefficients. All relevant coefficient estimates and 95% confidence interval values were exponentiated to return odds ratios (ORs) for the purpose of data interpretation.

We performed a sensitivity analysis with models adjusted for all key covariates with an additional adjustment for individual educational attainment at baseline to see if individual-level factors that were considered to be on the causal pathway had any influence on the estimates of the GEE models. Educational attainment was measured at the highest level of schooling completed, with three levels: a high school degree or less, some college, or a bachelor’s degree or further professional schooling.

All statistical analyses were performed using R Statistical Software (V4.2.1, R Core Team 2022) (60). GEE models were run using the “geeglm” function in the “geepack” package in R (61–63).

Results

Exclusion Criteria

Figure 1 provides details on exclusion criteria. We excluded individuals with missing data for key variables, such as our exposure (racial residential segregation), outcomes (smoking status and smoking intensity), and relevant covariates such as age, gender, birthplace, field center, and race and ethnicity. We then excluded 18 individuals who reported discrepant smoking status values throughout the five exams, such as reporting as a current smoker on an earlier exam, and a “never” smoker on a later exam. A total of 64 individuals were excluded for missing segregation data.

For our smoking intensity analytical model, we restricted our study population to only those with a current smoking status. We also excluded 170 discrepant observations from 134 unique current smokers who had missing smoking intensity over the study period. Our final smoking intensity sample consisted of 960 current smokers with a total of 2,931 observations.

Participant Characteristics

After accounting for exclusion criteria, our baseline sample of MESA participants consisted of 6,710 individuals. Over the five included exams, there were a total of 28,912 complete observations, averaging about four exams per participant. Tertile categories of segregation z-scores were as follows: Low RRS = (-0.638,0.072], Med RRS = (0.072,1.25], and High RRS = (1.25,6.6]. Mean segregation (z-score = 0) was observed in the “Low RRS” category. At baseline, individuals who reported being a current cigarette smoker were more likely to be male gender, Black race, born in the U.S., and have a younger age than the overall study population (Table 1). Current smokers made up 13% of the study population at baseline. Among current smokers, the median smoking intensity at baseline was 10 cigarettes smoked per day, with an interquartile range from 5 to 20 cigarettes (Table 1).

Over the course of the study period, 2,114 people (30%) were lost to follow-up due to death, relocation, or drop-out. The prevalence of current smokers in the study population decreased over time, from 13% at baseline to 8% at exam 5 (Table 2). Median smoking intensity remained consistent over time at 10 cigarettes per day.

Among racial and ethnic categories, White smokers reported the highest median smoking intensity, and Hispanic/Latinx smokers reported the lowest smoking intensity (Figure 2). There were no differences in smoking intensity between male and female smokers in the study population (Figure 3). Considering race and gender, White male smokers reported the highest smoking intensity (18 cigarettes) and Hispanic/Latinx female smokers reported the lowest smoking intensity (2.5 cigarettes) (Figure 4). While male and female smokers in each race category had a similar median smoking intensity, male smokers had a higher 75th percentile for smoking intensity (Figure 4).

Most White participants (54%) in the analysis lived in census tracts with low segregation, and most Chinese participants (56%) lived in census tracts with medium segregation (Table 3). Most Black (64%) and Hispanic/Latinx (41%) participants lived in high segregation areas (Table 3). As a result of spatially concentrated recruitment strategies in MESA, around 74% of those recruited from the Winston-Salem, NC field center lived in low segregation, and 62% of those recruited from the New York, NY field center lived in high segregation (Table 3). More U.S.-born participants lived in low segregation (40%), whereas most participants born outside of the U.S. lived in medium or highly segregated census tracts (42% and 41% respectively). While the low segregation category had a lower prevalence of current smokers than higher RRS categories, smokers living in low segregation had a higher median smoking intensity (Table 3).

Black participants across all segregation categories had the highest proportion of current smokers among all race and ethnicity categories (Figure 5). Black participants living in medium segregation had the highest proportion of current smokers out of all race and ethnicity and segregation categories (Figure 5). Like the distribution of Black current smokers, most Hispanic/Latinx current smokers lived in medium segregation (Figure 5). Among individuals in all racial and ethnic categories living in low and medium segregation, White participants had the highest proportion of current smokers who smoked at least a half a pack of cigarettes per day, with a median of 15 cigarettes (Figures 6 and 7). Among individuals living in high segregation, Chinese participants had the highest proportion of current smokers who reported smoking at least 10 cigarettes per day, among all racial categories (Figure 7). The proportion of current smokers who reported smoking 10 or more cigarettes per day decreased among White and Hispanic/Latinx individuals as RRS increased. Yet, the same proportion increased among Black and Chinese individuals as RRS increased.

Smoking Status

Among both medium and high RRS categories, the association between smoking status and segregation was stronger after we controlled for key covariates. Compared to participants who resided in low segregation, participants who lived in medium or high areas of segregation were significantly more likely to be current smokers, adjusted for baseline age, gender, race and ethnicity, birthplace, and field center. Participants living in medium segregation had 1.38 (95% CI: 1.13, 1.69) times higher odds of being a current smoker compared to participants living in low segregation (Table 4). Participants living in high segregation had 1.51 (95% CI: 1.21, 1.88) times higher odds of being a current smoker compared to participants living in low segregation areas, adjusted for covariates.

In stratified models, Black participants living in either medium (OR: 1.92, 95% CI: 1.24, 2.97) or high (OR: 1.59, 95% CI: 1.09, 2.32) segregation had statistically higher odds of being a current smoker than Black participants living in low segregation, adjusted for covariates (Table 4). Hispanic/Latinx individuals living in medium segregation had 1.63 (95% CI: 1.08, 2.48) times higher odds of being a current smoker than those living in low segregation. There were no other

statistically significant associations between RRS categories and smoking status among all other racial and ethnic groups.

When we adjusted for individual educational attainment in our sensitivity analysis, we found that risk estimates attenuated slightly. Individuals living in either high or medium segregation had about 1.3 times higher odds of being a smoker than an individual living in low segregation in fully adjusted models (Table 5).

Smoking Intensity

Results for the association between smoking intensity and RRS were null. While all confidence intervals included the null value, there appeared to be a very slight negative association between living in high segregation and reporting higher smoking intensity (OR: 0.96, 95% CI: 0.66, 1.40) (Table 6). In our stratified models, we similarly found null associations between RRS category and smoking intensity for all race and ethnicity categories. Adjusted for confounders, Hispanic/Latinx individuals living in high segregation had an odds ratio of 0.67 (95% CI: 0.33, 1.33) of smoking ten or more of cigarettes per day, compared to those living in low segregation.

Discussion

In this study of over 6,700 individuals across six large U.S. metropolitan areas, we found that individuals living in more racially segregated census tracts had significantly higher odds of reporting being current smokers than individuals living in less segregated areas. The overall odds of being a smoker were highest for people living in highly segregated neighborhoods, as compared to low segregated areas. When we look at the relationship between segregation and smoking status by race, we see different patterns. While there was no significant association for being a smoker among White and Chinese individuals living in various levels of segregation, Black and Hispanic/Latinx individuals generally had higher odds of reporting being a current smoker when living in more segregated areas.

Our a priori hypothesis was that factors such as stress (7,64–67), occupation (68,69), social environment (70), and discrimination (71) would lead to a positive association for both smoking status and smoking intensity with increased segregation. But we found no association between RRS and smoking intensity. One explanation for our null findings may be due to a lack of power, as our smoking intensity model only included data from 960 individuals with a total of 2,931 observations. There may also have been lingering measurement error in our smoking intensity variable, as we had to address multiple instances of improbable values for reported cigarettes per day in the past month (i.e., 400).

While previous studies on segregation and smoking have found a positive relationship between the likelihood of being a current smoker and living in higher segregation (26,36), there doesn't appear to be a consensus on the relationship between segregation and smoking intensity. Overall, Black, Asian, and Hispanic/Latinx individuals are more likely than non-Hispanic White

people to be light or intermittent cigarette smokers (3,4). Current smokers with a lower smoking intensity are also more likely to have higher educational attainment and perform other healthy behaviors, such as diet, than heavier smokers (3). A previous study on segregation and smoking found higher smoking intensity in racially integrated, low segregation areas, especially among White individuals (37). Another study found that Black individuals who moved from low segregation to high segregation during childhood were more likely to smoke more than those who had always lived in high segregation (30). We did not find any studies that could shed light on the differences between smoking status and smoking intensity among segregated neighborhoods, or that may explain a null association for smoking intensity. If the association for smoking intensity is truly null, we might hypothesize that environmental stressors due to segregation may not be strong enough to influence smoking frequency.

Even light smoking habits can have significant health consequences. A lower smoking intensity can still increase one's chances of developing cardiovascular disease and other smoking-related complications over time (3,72,73). Smoking fewer cigarettes per day is also associated with reporting a higher quality of life (74). Thus, we should still emphasize our findings of a significant association between high segregation and being a current smoker, even if there were no notable differences in smoking intensity. If people living in high segregation have higher odds of being a current smoker, then even a "light" smoking habit may still have negative health impacts. We might then speculate that people living in high segregation would have higher rates of smoking-related diseases than those living in low segregation due to having higher odds of reporting as a current smoker.

There were numerous strengths to this study. The few studies that have explored the relationship between segregation and smoking have used cross-sectional methods to complete their analyses (26,37). A major strength of our study is that we used longitudinal data from a large cohort to understand the relationship between segregation and smoking behaviors over time. While a bulk of the literature on segregation has mainly examined differences between White and Black racial categories (16), we included Chinese and Hispanic/Latinx individuals for a more diverse cohort. Considering other racial and ethnic groups is important because racialized minority groups in the U.S. may experience segregation differently. For example, Black pregnant mothers living in low segregation may be less likely to smoke during pregnancy as compared to those living in high segregation (75). Yet, the lowest probability of smoking during pregnancy among Asian and Hispanic/Latinx women was actually among those living in high segregation (75). Though the purpose of this study was not to comment on the potential benefits for living in clustered communities for some populations, we set out to study a diverse cohort to account for the multitude of experiences of living in racial residential segregation.

There were also a number of limitations of the study. As smoking behaviors were self-reported, it is possible that participants underreported their cigarette use due to social desirability bias. There is also some evidence to suggest that denial of smoking behaviors among current smokers may be differential by race and gender (76). We were unable to determine varying contextual, city-specific factors that may have influenced residential segregation, such as historic redlining policies, immigrant or ethnic enclaves, and gated or private communities,

among others. We also acknowledge that individual perception of one's neighborhood's racial makeup may vary within and between communities, and similar exposures of segregation may not equate to similar experiences with racial discrimination or psychosocial stress. Since the Divergence Index only offers one value for all residents of a neighborhood, we were unable to parse the key contextual differences that may exist between different racial groups living in similar levels of segregation. On its own, the Divergence Index does not distinguish between White and Black individuals living in high segregation, even if the contexts in which they live may differ widely.

We did not use pack-years or smoking duration (years of being a smoker) as outcome variables in this study, even though low cigarette use or short smoking duration can still have adverse health effects (77). This study did not investigate alternative forms of smoking, such as vaping, e-cigarettes, or other tobacco use, such as cigar or snuff use. This study also did not investigate smoking-related indicators such as urinary cotinine levels, cessation, or relapse. Future research should utilize a longitudinal design to investigate the impact of segregation on cigarette cessation and relapse, as these data would complement the growing literature of segregation and cigarette smoking.

It should be noted that since MESA participants were recruited from each field center through non-random sampling methods, the participants may not be representative of the race and ethnicity proportions, or spatial makeup of those areas. The sampling procedure also limited the variability of RRS in the sample population, as a random sample from a field center may have produced a more representative distribution of RRS scores. MESA researchers did not recruit people from all racial and ethnic categories from each field center, which may have led to differential variability in observations between groups. Individuals with cardiovascular disease were excluded from participation in the MESA study, which may have affected the generalizability of the results. As we know that smoking increases one's chances of developing cardiovascular disease (1), we acknowledge that there may be selection bias in our sample population that was free of CVD at baseline. We also acknowledge that the racial and ethnic categorizations in MESA were broad and may have been unreliable or inaccurate for each individual participant. Also, as MESA participants were between the ages of 45-84 at baseline, this study may not be applicable to factors regarding smoking initiation, which often occurs during adolescence (78).

The significant association between segregation and smoking status is a critically important piece for our collective understanding of the impacts of racial divergence on health. Our study should inform public health smoking interventions and generate discussion as to the ways that segregation remains a unique and fundamental cause of health disparities in the United States.

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Tables and Figures

Figure 1. Study Sample Exclusion Criteria

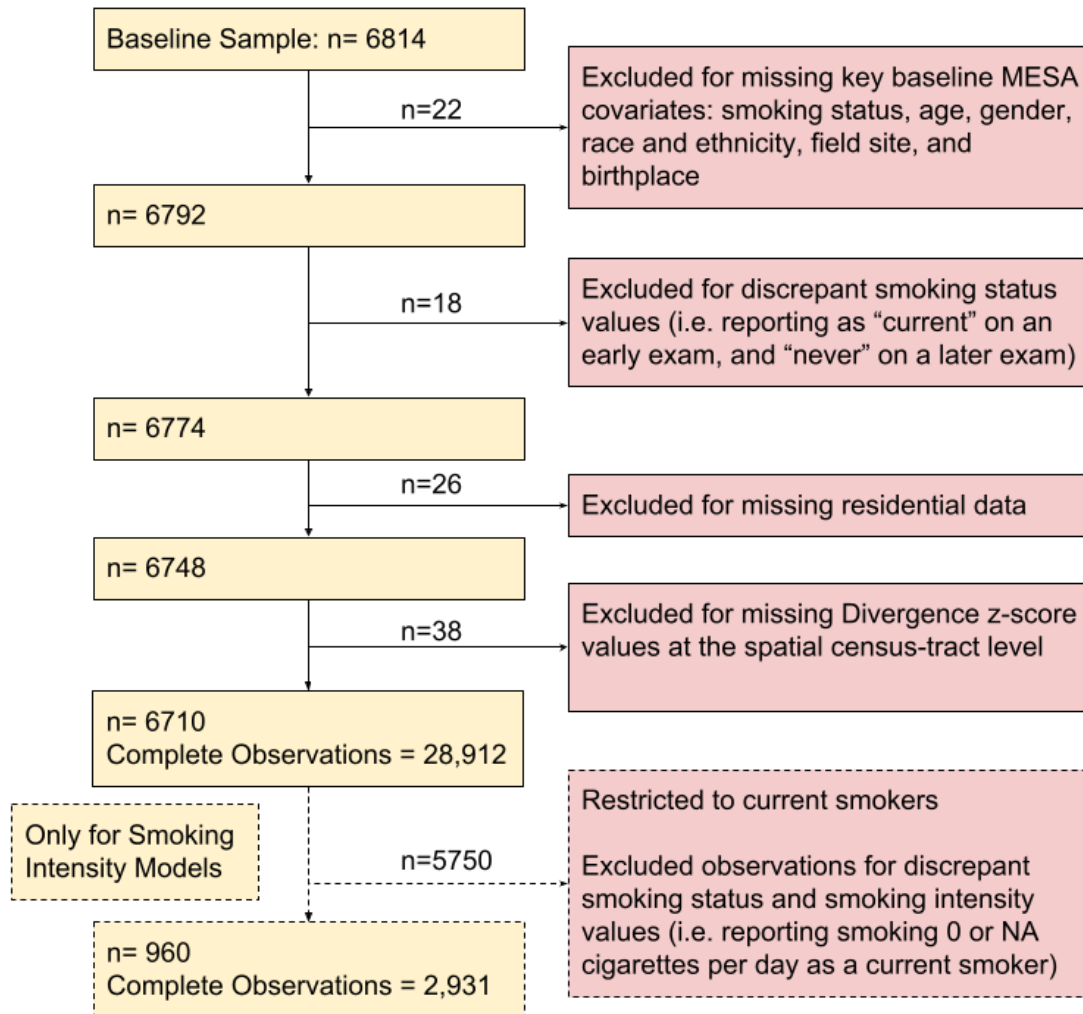


Table 1. Baseline Characteristics by Smoking Status

Variable ¹	Never (N = 3383, 50%)	Former (N = 2451, 37%)	Current (N = 876, 13%)	Overall, N = 6,710
Gender, n (%)				
Female	2,101 (62%)	1,034 (42%)	416 (47%)	3,551 (53%)
Male	1,282 (38%)	1,417 (58%)	460 (53%)	3,159 (47%)
Age (years), Mean (SD)	62 (11)	63 (10)	58 (9)	62 (10)
Race and Ethnicity, n (%)				
White	1,144 (34%)	1,138 (46%)	298 (34%)	2,580 (38%)
Chinese	599 (18%)	152 (6%)	45 (5%)	796 (12%)
Black	841 (25%)	687 (28%)	334 (38%)	1,862 (28%)
Hispanic/Latinx	799 (24%)	474 (19%)	199 (23%)	1,472 (22%)
Field Center, n (%)				
Winston-Salem, NC	463 (14%)	433 (18%)	149 (17%)	1,045 (16%)
New York, NY	557 (16%)	381 (16%)	151 (17%)	1,089 (16%)
Baltimore, MD	486 (14%)	423 (17%)	152 (17%)	1,061 (16%)
St. Paul, MN	465 (14%)	416 (17%)	170 (19%)	1,051 (16%)
Chicago, IL	598 (18%)	436 (18%)	124 (14%)	1,158 (17%)
Los Angeles, CA	814 (24%)	362 (15%)	130 (15%)	1,306 (19%)

Variable¹	Never (N = 3383, 50%)	Former (N = 2451, 37%)	Current (N = 876, 13%)	Overall, N = 6,710
Birthplace, n (%)				
U.S. ²	2,094 (62%)	1,966 (80%)	695 (79%)	4,755 (71%)
Another Country ³	1,289 (38%)	485 (20%)	181 (21%)	1,955 (29%)
Cigarettes Per Day, Median (IQR)	NA (NA, NA)	NA (NA, NA)	10 (5, 20)	10 (5, 20)

¹Cell percentages calculated by column

²Participants born in Puerto Rico categorized as born in the U.S.

³Participants reported 91 different birth countries other than the U.S.

Table 2. Smoking Behaviors by Exam

Variable ¹	Exam 1 (N = 6710, 23%) ²	Exam 2 (N = 6114, 21%) ²	Exam 3 (N = 5844, 20%) ²	Exam 4 (N = 5648, 20%) ²	Exam 5 (N = 4596, 16%) ²	Overall (N = 28912, 100%) ³
Smoking Status, n (%)						
Never	3,383 (50%)	2,829 (46%)	2,650 (45%)	2,538 (45%)	2,070 (45%)	13,470 (47%)
Former	2,451 (37%)	2,594 (42%)	2,572 (44%)	2,558 (45%)	2,166 (47%)	12,341 (43%)
Current	876 (13%)	691 (11%)	622 (11%)	552 (10%)	360 (8%)	3,101 (11%)
Cigarettes Per Day Among Current Smokers, Median (IQR)	10 (5, 20)	10 (5, 20)	10 (5, 20)	10 (5, 20)	10 (5, 15)	10 (5, 20)
Cigarettes Per Day Among Current Smokers, n (%)						
<10 cigarettes per day	296 (34%)	242 (35%)	216 (35%)	222 (40%)	139 (39%)	1,115 (36%)
>= 10 cigarettes per day	538 (61%)	405 (59%)	372 (60%)	311 (56%)	190 (53%)	1,816 (59%)
Missing ⁴	42 (5%)	44 (6%)	34 (5%)	19 (3%)	31 (9%)	170 (5%)

¹Cell percentages calculated by column

²Missing values for smoking status excluded for each exam

³Overall N is a total sum of complete observations across five exams, and not the total number of participants in the study

⁴Participants who reported as a current smoker but reported zero or were missing cigarettes per day

Table 3. Baseline Characteristics by Racial Residential Segregation

Variable ¹	Low RRS (N = 2237, 33%) ²	Med RRS (N = 2239, 33%) ²	High RRS (N = 2234, 33%) ²	Overall (N = 6710, 100%) ²
Race and Ethnicity, n (%)				
White	1,402 (54%)	1,010 (39%)	168 (7%)	2,580 (100%)
Chinese	76 (10%)	448 (56%)	272 (34%)	796 (100%)
Black	369 (20%)	299 (16%)	1,194 (64%)	1,862 (100%)
Hispanic/Latinx	390 (26%)	482 (33%)	600 (41%)	1,472 (100%)
Field Center, n (%)				
Winston-Salem, NC	771 (74%)	83 (8%)	191 (18%)	1,045 (100%)
New York, NY	229 (21%)	182 (17%)	678 (62%)	1,089 (100%)
Baltimore, MD	364 (34%)	283 (27%)	414 (39%)	1,061 (100%)
St. Paul, MN	475 (45%)	493 (47%)	83 (8%)	1,051 (100%)
Chicago, IL	201 (17%)	597 (52%)	360 (31%)	1,158 (100%)
Los Angeles, CA	197 (15%)	601 (46%)	508 (39%)	1,306 (100%)
Birthplace, n (%)				
U.S. ³	1,899 (40%)	1,422 (30%)	1,434 (30%)	4,755 (100%)
Another Country ⁴	338 (17%)	817 (42%)	800 (41%)	1,955 (100%)
Cigarettes per day, Median (IQR)	15 (7, 20)	10 (5, 20)	10 (5, 17)	10 (5, 20)

Variable¹	Low RRS (N = 2237, 33%)²	Med RRS (N = 2239, 33%)²	High RRS (N = 2234, 33%)²	Overall (N = 6710, 100%)²
Smoking Status, n (%)				
Never	1,068 (32%)	1,161 (34%)	1,154 (34%)	3,383 (100%)
Former	916 (37%)	795 (32%)	740 (30%)	2,451 (100%)
Current	253 (29%)	283 (32%)	340 (39%)	876 (100%)

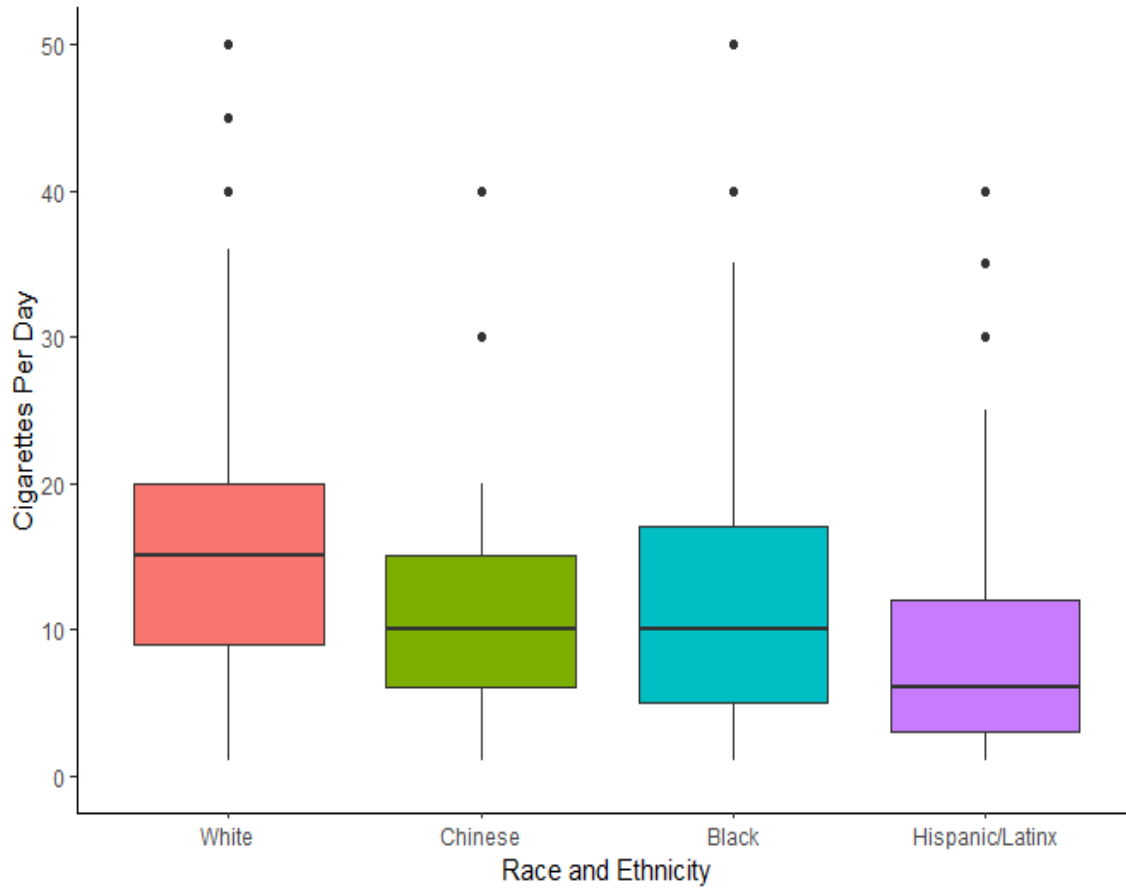
¹Cell percentages calculated by row

²RRS = Racial Residential Segregation, measured as Spatial Divergence Z-score category (Census Tract).
Tertiles of Divergence z-scores are as follows: Low = (-0.64,0.07], Med = (0.07,1.25], High = (1.25,6.60]

³Participants born in Puerto Rico categorized as born in the U.S.

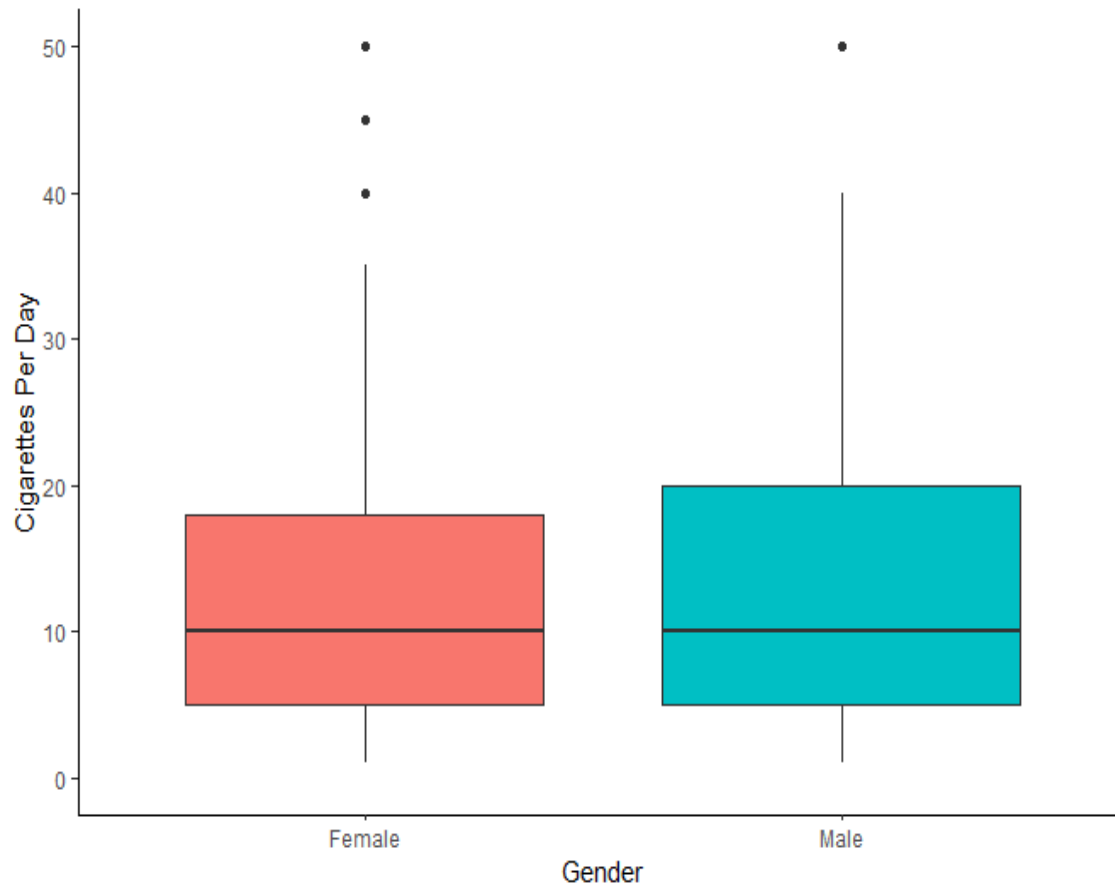
⁴Participants reported 91 different birth countries other than the U.S.

Figure 2. Cigarettes Per Day Among Current Smokers by Race and Ethnicity



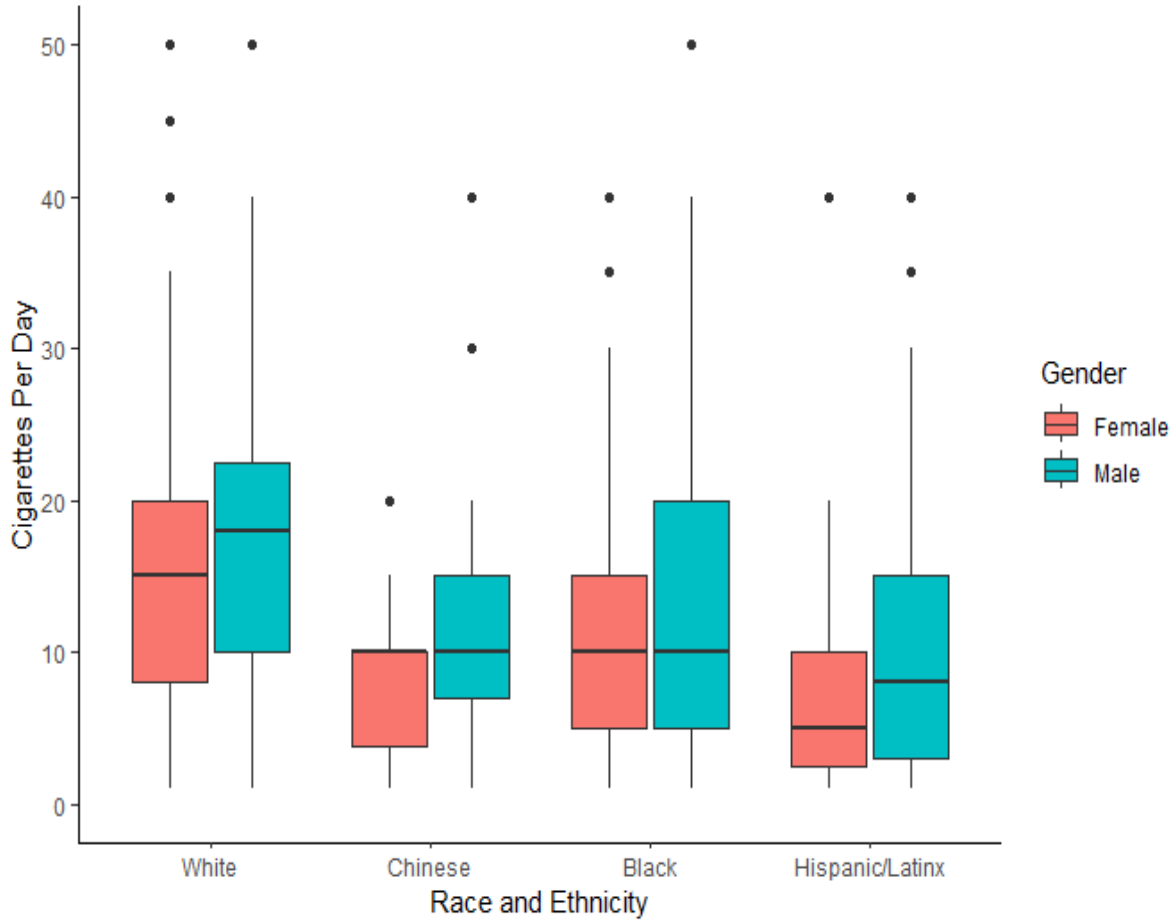
2 outlier values were excluded in figure.

Figure 3. Cigarettes Per Day Among Current Smokers by Gender



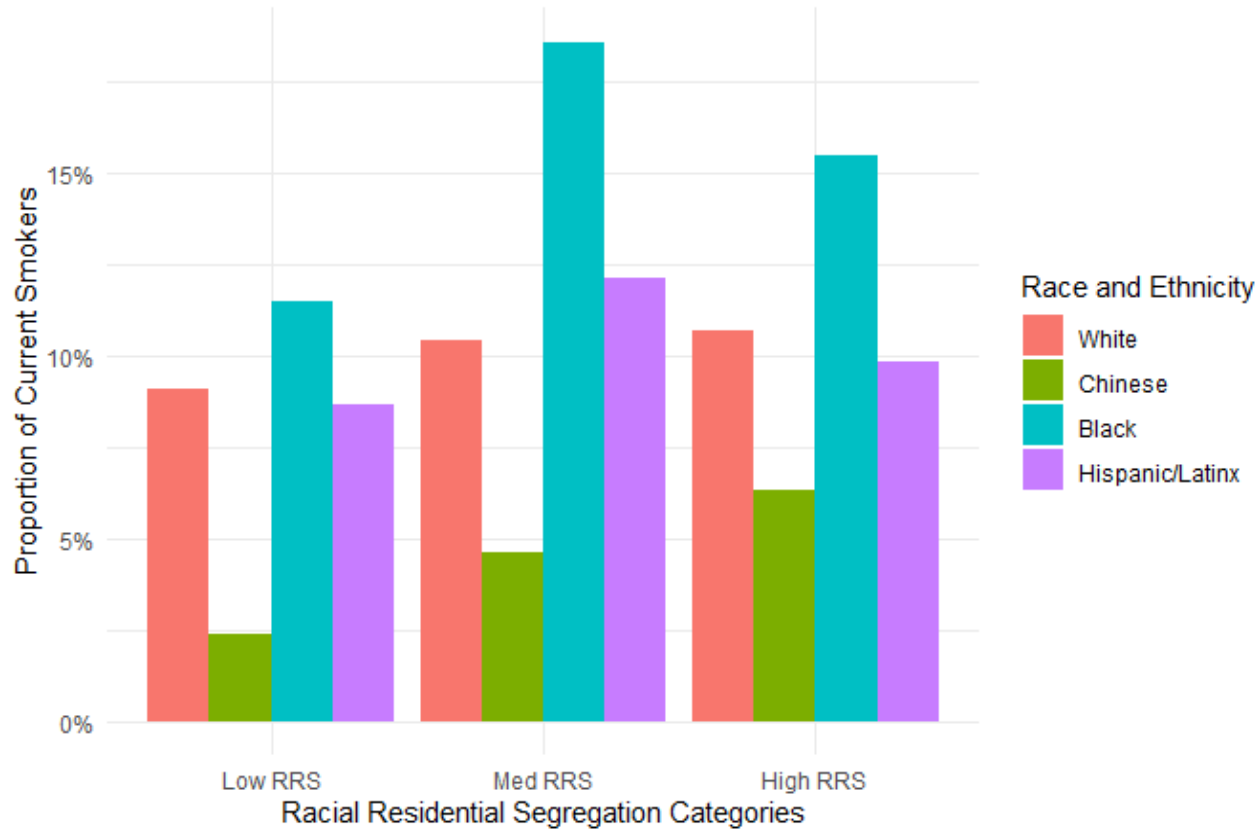
2 outlier values were excluded in figure.

Figure 4. Cigarettes Per Day Among Current Smokers by Race and Ethnicity and Gender



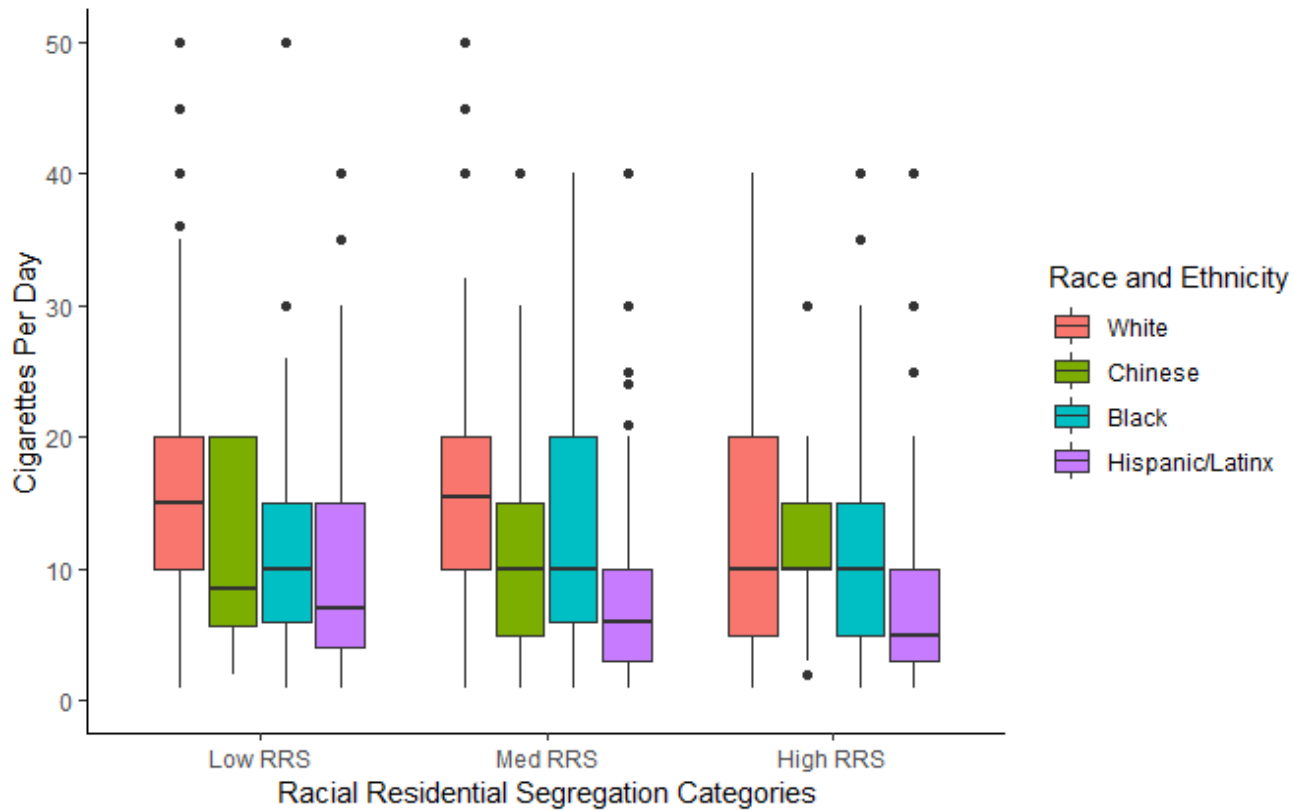
2 outlier values were excluded in figure.

Figure 5. Proportion of Current Smokers by Race and Ethnicity and Racial Residential Segregation



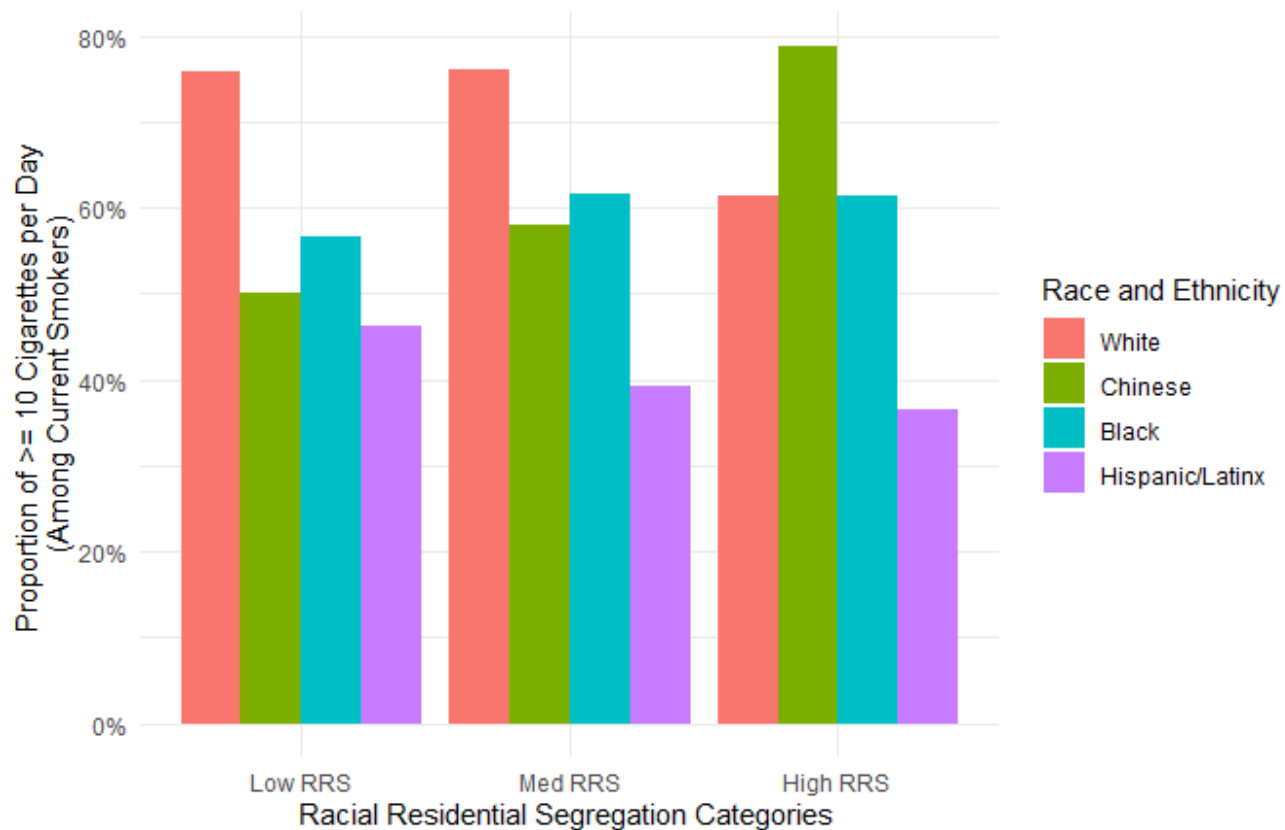
Racial Residential Segregation was measured as Spatial Divergence Z-Score Category (Census Tract-level)

Figure 6. Cigarettes Per Day by Racial Residential Segregation and Race and Ethnicity



2 outlier values were excluded in figure.
 Racial Residential Segregation was measured as
 Spatial Divergence Z-Score Category (Census Tract-level)

Figure 7. Proportion of Smoking ≥ 10 Cigarettes Per Day by Race and Ethnicity and Racial Residential Segregation



Racial Residential Segregation was measured as Spatial Divergence Z-Score Category (Census Tract-level)

Table 4. Odds Ratios and 95% Confidence Intervals for Current Smoking Status Among Racial Residential Segregation Categories

Level	Overall (obs=28912) ^a	White (obs=11475) ^b	Black (obs=7820) ^b	Chinese (obs=3395) ^b	Hispanic/Latinx (obs=6222) ^b
Low RRS	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Med RRS	1.38 (1.13,1.69)	1.16 (0.86,1.57)	1.92 (1.24,2.97)	2.56 (0.64,10.14)	1.63 (1.08,2.48)
High RRS	1.51 (1.21,1.88)	1.42 (0.87,2.31)	1.59 (1.09,2.32)	3.19 (0.77,13.15)	1.39 (0.87,2.22)

RRS=Racial Residential Segregation, measured as Spatial Divergence Z-Score Category (Census Tract).^aAdjusted for baseline values for age, gender, race and ethnicity, birthplace, and field center.; ^bAdjusted for baseline values for age, gender, birthplace, and field center;

Table 5. Odds Ratios and 95% Confidence Intervals for Current Smoking Status
Among Racial Residential Segregation Categories

Level	Adjusted Model ^a	Adjusted Sensitivity Model ^b
Low RRS	1.00 (ref)	1.00 (ref)
Med RRS	1.38 (1.13,1.69)	1.31 (1.07,1.61)
High RRS	1.51 (1.21,1.88)	1.32 (1.05,1.64)

RRS=Racial Residential Segregation, measured as Spatial Divergence Z-Score Category (Census Tract). ^aAdjusted for baseline values for age, gender, race and ethnicity, birthplace, and field center.; ^bAdjusted for baseline values for age, gender, race and ethnicity, birthplace, field center, and educational attainment;

Table 6. Odds Ratios and 95% Confidence Intervals for Reporting ≥ 10 Cigarettes Per Day
Among Current Smokers by Racial Residential Segregation Categories

Level	Overall (obs=2931) ^a	White (obs=1045) ^b	Black (obs=1141) ^b	Chinese (obs=167) ^b	Hispanic/Latinx (obs=578) ^b
Low RRS	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Med RRS	0.90 (0.63,1.27)	1.11 (0.63,1.96)	1.20 (0.61,2.35)	0.92 (0.12,7.15)	0.76 (0.37,1.57)
High RRS	0.96 (0.66,1.4)	0.71 (0.29,1.76)	1.02 (0.58,1.82)	2.89 (0.43,19.34)	0.67 (0.33,1.33)

RRS=Racial Residential Segregation, measured as Spatial Divergence Z-Score Category (Census Tract).^aAdjusted for baseline values for age, gender, birthplace, field center, and race and ethnicity.; ^bAdjusted for baseline values for age, gender, birthplace, and field center.;