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Authors
Woo, Bongki
Kravitz-Wirtz, Nicole
Sass, Victoria
et al.

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Residential Segregation and Racial/Ethnic Disparities in Ambient Air Pollution

Bongki Woo, PhD, MSW,
College of Social Work, University of South Carolina, 1512 Pendleton Street, Columbia, SC, 29208

Nicole Kravitz-Wirtz, PhD, MPH,
Department of Emergency Medicine, University of California, Davis

Victoria Sass,
Department of Sociology, University of Washington, Seattle

Kyle Crowder, PhD,
Department of Sociology, University of Washington, Seattle

Samantha Teixeira, PhD, MSW,
School of Social Work, Boston College

David T. Takeuchi, PhD, MA
School of Social Work, Boston College

Abstract

Race and ethnicity are consequential constructs when it comes to exposure to air pollution. Persistent environmental racial/ethnic inequalities call for attention to identifying the factors that maintain them. We examined associations between racial residential segregation and racial/ethnic inequalities in exposure to three types of air pollutants. Using data from the Panel Study of Income Dynamics (1990-2011), the U.S. Census (1990- 2010), and the Environmental Protection Agency, we tested the independent and joint contributions of race/ethnicity and metropolitan-level residential segregation on individual levels of exposure to air pollution nationwide. We found that racial and ethnic minorities were exposed to significantly higher levels of air pollution compared to Whites. The difference between minorities and Whites in exposure to all three types of air pollution was most pronounced in metropolitan areas with high levels of residential segregation. The environmental inequities observed in this study call for public health and policy initiatives to ameliorate the sources of racial/ethnic gaps in pollution exposure. Given the links between the physical environment and health, addressing such uneven environmental burdens may be a promising way to improve population health and decrease racial/ethnic inequalities therein.

Keywords

Air Pollution; Race and Ethnicity; Residential Segregation; Nitrogen Oxides; Particulate Matter

Corresponding Author: Phone: 803-777-3511, woob@mailbox.sc.edu.

Conflict of Interest The authors declare that they have no conflict of interest.

Introduction

Clean air is a basic but taken-for-granted necessity for healthy human development. Yet this vital resource is not evenly distributed across society. Some groups and geographic areas are more likely than others to be exposed to environmental hazards that may severely compromise air quality with important consequences for individual health and welfare. For instance, the association between air pollution and various adverse health outcomes, particularly morbidity and mortality from cardiovascular and respiratory diseases, has been well-documented in past research (Pope III and Dockery 2006). This is also a critical policy area, as efforts to roll back federal environmental protections may exacerbate the unequal distribution of environmental and, by extension, health and health care burdens at the state and local levels.

Race and ethnicity are particularly consequential constructs when it comes to exposure to air pollution. A previous longitudinal study indicates that although levels of air pollution have decreased over time for all racial/ethnic groups, racial/ethnic gaps in exposure persist today: on average, Blacks and Latino/as tend to be exposed to substantially higher levels of multiple types of air pollutants than those experienced by Whites (Kravitz-Wirtz et al. 2016). These persistent environmental racial/ethnic inequalities call for attention to identifying the factors that maintain them.

Explanations for the associations between race, place, and the physical environment have been described in detail elsewhere (Crowder and Downey 2010; Downey 2007; Downey et al. 2008; Gee and Payne-Sturges 2004; Kravitz-Wirtz et al. 2016; Ogbu 1978). In brief, various political, socioeconomic, and discriminatory forces have concentrated people of color within distinct and often socioeconomically disadvantaged neighborhoods in which they are also disproportionately exposed to environmental hazards, including ambient air pollution. Polluting industries are more often located in disenfranchised communities, in which people of color disproportionately reside, as residents of these areas often have fewer resources and social capital, and limited power to affect the decision-making processes that determine where such industries are placed (Gee and Payne-Sturges 2004). The entry of these industries can cause a cycle of vulnerability in communities that can decrease property values and negatively affect infrastructure and social capital, which may in turn pave the way for more polluting facilities (Elliott and Frickel 2013).

In addition, differential enforcement of environmental regulations, such as racialized zoning policies, property laws, or practices of credit rationing in disadvantaged majority-minority neighborhoods and politically underrepresented communities has been shown to facilitate the entry of polluting industries (Gee and Payne-Sturges 2004; Jones et al. 2015; Pulido 2000). While current regulations may not be as deliberately discriminatory as they were in the past, new industrial facilities nonetheless tend to be sited in communities occupied by people of color as the result of past discriminatory zoning decisions (Gee and Payne-Sturges 2004). Moreover, racial discrimination in the housing market may limit the residential mobility of people of color and keep them concentrated in polluted neighborhoods, even if they have the financial means to move (Gee and Payne-Sturges 2004; Taylor 2014). These theoretical explanations imply that macrosocial factors, particularly housing and residential segregation, may play an important role in racial/ethnic disparities in air pollution exposure.

Accordingly, patterns of racial residential segregation may exacerbate racial/ethnic inequalities in exposure to air pollution by creating contexts for differential, often worse, physical environments in which racial/ethnic minorities are concentrated, as well as limiting their ability to move away from polluted areas (Downey et al. 2008; Jones et al. 2015; Lopez 2002). As residential segregation is associated with the spatial concentration of poverty and lack of socioeconomic opportunities (Williams and Collins 2001), it can perpetuate power differentials between minority and majority communities which influence decisions about the siting of hazardous pollution sources (Massey and Denton 1993; Morello-Frosch and Lopez 2006). Further, segregation can result in spatial segmentation between neighborhoods within metropolitan areas, and hence can increase the amount of driving and commute times, which can increase air pollution derived from mobile sources (Ash et al. 2012; Morello-Frosch and Jesdale 2005). Overall, then, we posit that residential segregation may exacerbate exposure to air pollution, particularly among racial/ethnic minority populations.

However, to date, only a handful of studies have examined the relationships among race/ethnicity, racial residential segregation, and exposure to air pollution, and most have relied only on aggregate-level data (Downey et al. 2008; Jones et al. 2015; Lopez 2002). Thus, previous research provides limited information on variations in individual exposure to air pollution and on whether or how individual and metropolitan-level factors intersect to influence this exposure (Ash and Fetter 2004; Downey 2005).

To address this gap, we use over two decades of nationally-representative data on individual respondents combined with census data on metropolitan areas and spatially-precise measures of neighborhood air pollution to examine the independent and joint impacts of race/ethnicity and racial residential segregation on inequalities in air pollution exposure. A focus on the intersection of race/ethnicity and racial residential segregation offers new possibilities for understanding how inequitable group relations at the individual and contextual levels contribute to and compound environmental inequalities by race/ethnicity, as well as their health-related sequelae, including lung inflammation, respiratory infection and illness, and heart disease (Kampa and Castanas 2008).

Methods

Study Data

Individual-level data come from the 1990 to 2011 waves of the Panel Study of Income Dynamics (PSID), a longitudinal, replenishing survey of U.S. residents and their families conducted annually between 1968 and 1997 and biennially thereafter. Respondents are followed over time, regardless of residential mobility. Analyses focused on 3,520 PSID respondents from four racial/ethnic groups: Asians, Blacks, Latino/as and Whites (N = 19,299 person-periods). Race/ethnicity was defined based on respondents’ self-identification. We exclude Native American respondents due to insufficient numbers in the PSID.

Using the PSID's supplemental, restricted-use Geospatial Match Files, we link individual PSID records with measures of neighborhood air pollution at each interview year, specifically annual-average concentrations of nitrogen dioxide (NO_2), coarse particulate matter (PM_{10}), and fine particulate matter ($PM_{2.5}$) in respondents' census blocks of residence. NO_2 is emitted when fossil fuel is burned in transport, industrial processes, or power generation and is considered a measure of traffic-related air pollution. PM_{10} and $PM_{2.5}$ result from construction sites, dust from unpaved roads, fields, and chemical reactions involving primarily gaseous emissions (United States Environmental Protection Agency n.d.). NO_2 is measured in parts per billion (ppb), while PM_{10} and $PM_{2.5}$ are measured in micrograms per cubic meter (u/m^3).

These pollution measures are derived from the Environmental Protection Agency's (EPA) Air Quality System (AQS), a database with criteria air pollutant measurements collected from a nationwide network of monitoring stations. The AQS provides a more reliable and comprehensive assessment of local air quality, and variations therein, compared to other widely-used databases such as the Toxics Release Inventory (TRI), which relies on self-reports from polluters and excludes pollution from non-industrial sources, including vehicles. Nonetheless, a key challenge in using the AQS is that air quality monitoring stations are not located evenly across the nation and vary across time. Consistent with several recent epidemiological studies of air pollution and health (Chan et al. 2015; Chi et al. 2016; Liu et al. 2016; Reding et al. 2015; Young et al. 2014), we address this issue by using a combination of land-use regression and universal kriging to spatially interpolate reliable annual-average pollutant concentrations in every neighborhood in which PSID respondents resided at each interview year during the study period (Sampson et al. 2013).

Regression models that use geographic characteristics as predictors are termed "land-use" regression. Our model is based on a database of over 265 geographic covariates which are related to small-scale variation in air quality, including population density, total emissions of criteria air pollutants, land use, the normalized difference vegetation index (NDVI), measures of impervious surfaces, distance to and length of major roadways, and distance to commercialized zones, airports, and railroads (Sampson et al. 2013). Universal kriging is a spatial smoothing technique that takes into account spatial autocorrelation (statistical relationships among adjacent points) and facilitates estimation of annual-average air pollutant concentrations for any given location in the country, regardless of its distance from an AQS monitor (Sampson et al. 2011). Since the smallest unit of geography available for PSID respondents is the census block, this approach was used to derive pollution estimates at the centroid of respondents' residential census blocks, as a proxy for individual exposure, for each interview year between 1990 and 2011.

We also attach information on metropolitan-level racial residential segregation (hereafter segregation) as defined by the index of dissimilarity, a measure of the relative separation of a racial/ethnic minority group from Whites across all census tracts ("neighborhoods") of a given metropolitan area (Massey and Denton 1988). A lower value on the dissimilarity index indicates that a minority group and Whites are more evenly distributed across neighborhoods in a metropolitan area (i.e., less segregated). This index was derived for Asians, Blacks, and Latinos/as (relative to Whites) from measures of racial/ethnic composition at the census tract and metropolitan statistical area (MSA) levels for the 1990, 2000, and 2010 censuses, with linear interpolation for intervening years.

Statistical Analysis

To examine the independent and joint contributions of race/ethnicity and segregation on inequalities in exposure to neighborhood air pollution, we organize our data into a series of person-period observations, with each observation referring to the one or two-year period between PSID interviews. On average, respondents contribute information at 5.48 time periods. Having pooled our data across years, we fit a series of linear regression models using ordinary least squares. First, we test the bivariate association between individual race/ethnicity and block-level exposure to each pollutant (Model 1). Model 2 adds metropolitan-level measures of residential segregation of Blacks, Latino/a's, and Asians from Whites. Finally, in Model 3, we include an cross-level interaction term between race/ethnicity and segregation to test the moderating role of segregation on racial gaps in air pollution exposure (Aguinis, Gottfredson, and Culpepper 2013; Preacher, Patrick, and Bauer 2006; Raudenbush and Bryk 2002). Here, we interact group-specific segregation scores with individual race/ethnicity (e.g., interact Asian-White segregation with the dummy variable for Asian). In all models, we calculate robust standard errors to account for the non-independence of observations for the same respondent across years. All coefficients are presented unstandardized and are therefore in the original units of the variables.

Study Results

Consistent with past research, bivariate analyses of the relationship between race/ethnicity and each of the three air pollutants indicate that individuals of color are exposed to significantly higher levels of air pollution compared to Whites. Specifically, Whites reside in neighborhoods with, on average, 14.09 ppb, 22.35 u/m^3, and 13.13 u/m^3 of NO_2, PM_{10}, and $PM_{2.5}$, respectively (Model 1, Table 1). Blacks and Latino/as, on the other hand, reside in neighborhoods with, on average, between 2% and 40% higher concentrations of each pollutant. Asian respondents are also exposed to significantly higher concentrations of neighborhood NO_2 and PM_{10} compared to Whites, although $PM_{2.5}$ levels are not statistically different.

In general, metropolitan-level segregation is also significantly associated with higher levels of exposure to all three ambient air pollutants, over and above the influence of race/ethnicity (Model 2, Table 1). There are three exceptions wherein residing in areas characterized by greater segregation of Asians from Whites is linked to lower levels of NO_2 (b = −1.5, p<.01), and areas with greater segregation of Latino/as from Whites is related to significantly lower levels of both PM_{10} (b = −4.55, p<.01) and $PM_{2.5}$ (b = −6.59, p<.01).

Last, all the interactions between race/ethnicity and the corresponding segregation measures (e.g., Black*Black-White segregation) are statistically significant, except for the interaction term between Asian*Asian-White segregation for PM_{10} (Model 3, Table 1). These interaction terms suggest an added pollution burden for racial/ethnic group members who reside in areas in which their group is more highly segregated from Whites. Specifically, we observe larger racial/ethnic inequities in exposure to all three types of air pollution when segregation from Whites is greater.

Figures 1 to 3 reflect exposure to each air pollutant among racial/ethnic groups residing in metropolitan areas with low (10th percentile), average (50th percentile), and high (90th percentile) levels of segregation . For comparison, we include a horizontal reference line indicating the average level of pollution faced by Whites across all metropolitan areas. The results indicate that exposures to all three types of air pollution, and the contrast with the pollutant exposures experienced by Whites, are most pronounced in metropolitan areas in which members of a given minority group are highly segregated from Whites.

Discussion

This study highlights that racial residential segregation, when operationalized as a measure of dissimilarity, contributes to racial/ethnic inequalities in individual exposure to neighborhood air pollution. That communities of color face greater threats to the air they breathe is noteworthy because it aligns with strong evidence of unequal, often worse, health status among racial/ethnic minorities. Our findings indicate that segregation from the dominant racial group can intensify the ambient environmental burden and pollution-related health risks among racial/ethnic minorities. Moreover, these issues are even more urgent in light of recent efforts to dismantle federal environmental protections, such as the Clean Power Plan, and proposals to cut the federal budget for programs at the EPA that promote environmental justice.

Consistent with past research, our study confirms that racial/ethnic minorities (vs. Whites) are exposed to greater concentrations of three types of air pollutants in their residential neighborhoods (Kravitz-Wirtz et al. 2016). Such disproportionately high levels of air pollution exposure among racial/ethnic minorities suggests that federal cuts to environmental protections will likely take a heavier toll on people of color in jurisdictions that have experienced greater structural racism and discrimination, and may also hamper ongoing efforts to reduce disparities in environmental burden and associated health-related outcomes at the state and local levels.

In addition, we find that racial residential segregation is associated with higher levels of exposure to all three air pollutants. With few exceptions, individuals living in more racially segregated metropolitan areas were more likely to be exposed to air pollutants, indicating that air pollution is both racially and spatially concentrated. This is consistent with theoretical arguments positing that areas where people of color disproportionately reside tend to have more polluting industries, and that racialized zoning and property laws may limit the residential choices of people of color to more polluted areas (Mohai and Saha 2015; Morello-Frosch and Lopez 2006).

Interestingly, we found that areas with higher Latino/a-White segregation had lower levels of $PM_{2.5}$ and PM_{10}, and that areas with higher Asian-White segregation displayed lower NO_2 concentrations. These results may reflect the concentration of Asians or Latino/as in areas outside the industrial core, which decreases average neighborhood-level exposure levels for all residents of the metropolitan area. It is also possible that segregation may concentrate not only risks but also social and political resources, which can empower communities to protect themselves from new environmental threats or find solutions to remediate existing hazards (Gee and Payne-Sturges 2004). Given that the association between segregation and air pollution remains relatively understudied, future studies evaluating this inconsistency more fully would be beneficial.

We also identified the joint contribution of race/ethnicity and segregation to levels of exposure to neighborhood air pollutants, documenting that spatial separation from the majority group concentrates environmental hazards among minority individuals. Overall, the racial/ethnic gap in pollution exposure is larger in areas where segregation is higher, indicating that segregation not only serves to keep minorities in separate residential spaces, but also keeps them more proximate to the sources of pollution. This is a noteworthy finding as residential segregation may provide a partial explanation for why minority communities have been shown to be more susceptible to the health effects of air pollution (Morello-Frosch and Jesdale 2005). It also strengthens the empirical foundation on which to base future research on the association of residential segregation with unequal environmental health outcomes, such as cardiovascular and respiratory disease prevalence, hospital visits, and death (Akinbami et al. 2012). Moreover, our findings suggest that efforts to reduce racial/ethnic disparities in pollution exposure should be accompanied by attempts to decrease residential segregation.

Our findings indicate that air quality monitoring and efforts to reduce emission sources can be enhanced particularly in segregated neighborhoods (Morello-Frosch and Shenassa 2006). Building community partnership would be crucial for identifying smaller emission sources and to understand effective ways for regulating pollution sources within local socioeconomic contexts. In addition, recognizing that metropolitan-level residential segregation is an important driver of environmental health inequities, regional authorities and community stakeholders can promote comprehensive policies that can help to address structural inequalities by improving the neighborhood built environment, land use planning, and transportation policies, and strengthening fair housing laws and housing affordability (Morello-Frosch and Shenassa 2006; Orfield 2005). It is important to note, however, that these concerted efforts need to be implemented across metropolitan areas or larger geographic scales, because land-use policies, for example, at a smaller geographic scale can increase urban sprawl, which can lead in turn to segregation by encouraging leapfrog development (Orfield 2005).

Our findings also highlight the importance of racial-environmental justice efforts in the context of the Trump administration’s attempts to roll back both health and environmental protections. Higher levels of air pollutants in areas concentrated with more racial/ethnic minorities may have significant effects on their health. The environmental inequities observed in this study not only underscore the need for additional research into the fundamental drivers of such inequities, but also call for public health and policy initiatives that can ameliorate the sources of environmental inequality.

Our study extends the current knowledge base in that it uses a national sample and has more power to detect the link between residential segregation and exposure to air pollutants compared to previous studies. In addition, we use comprehensive and spatially-precise estimates of air pollution to which individuals were exposed at multiple points over 20 years. However, the findings of this study should also be considered in light of the following limitations. First, levels of air pollution are measured at the centroid of respondents' residential census blocks, as this is the smallest geographical unit available in the PSID. Future studies will benefit from the use of even more temporally and spatially-resolved measures of individual toxic exposure (e.g., cell phone applications that track movement throughout the day or body-worn devices that monitor toxic exposures). Second, we operationalized residential segregation by using the dissimilarity index, which captures spatial separation between minorities and Whites. While this measure is widely used, future studies may benefit from the use of other dimensions (e.g., isolation) and other measures of segregation (e.g., index of concentration at the extremes) (Massey and Denton 1988; Krieger et al. 2016). Third, while our study focused on air pollution, future studies can extend this line of research by exploring the effect of race/ethnicity and segregation on other types of pollution, such as water or soil contamination.

Despite the limitations, this study provides evidence that race/ethnicity and racial residential segregation matter when it comes to exposure to ambient air pollution. Specifically, segregation of racial/ethnic minorities from the majority group is associated with additional burdens of air toxic exposure among these marginalized communities, and in turn, may exacerbate racial health disparities. Results of this study underscore the importance of community and policy efforts to achieve environmental justice. Given well-documented links between the physical environment and health, addressing such environmental injustices would be a promising way to improve population health and reduce or eliminate racial/ethnic inequalities therein (Crowder and Downey 2010; Downey 2007; Downey et al. 2008; Gee and Payne-Sturges 2004; Kravitz-Wirtz et al. 2016; Ogbu 1978).

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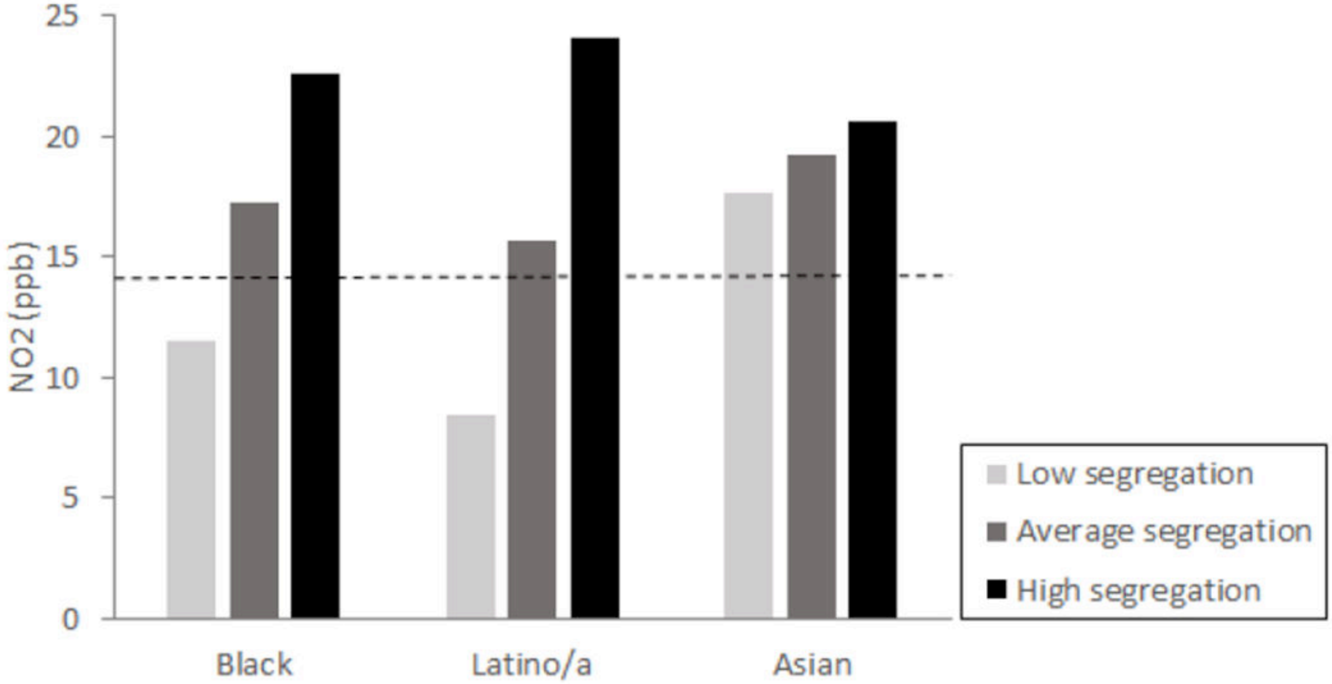

Figure 1. Neighborhood-Level NO_2 Exposure by Different Levels of Residential Segregation

SOURCE Authors' analysis of data from the Panel Study of Income Dynamics (1990-2011), Environmental Protection Agency, and U.S. Census (1990-2010). **NOTES** Low segregation refers to the 10^{th} percentile of the dissimilarity index. High segregation refers to the 90^{th} percentile of the dissimilarity index.

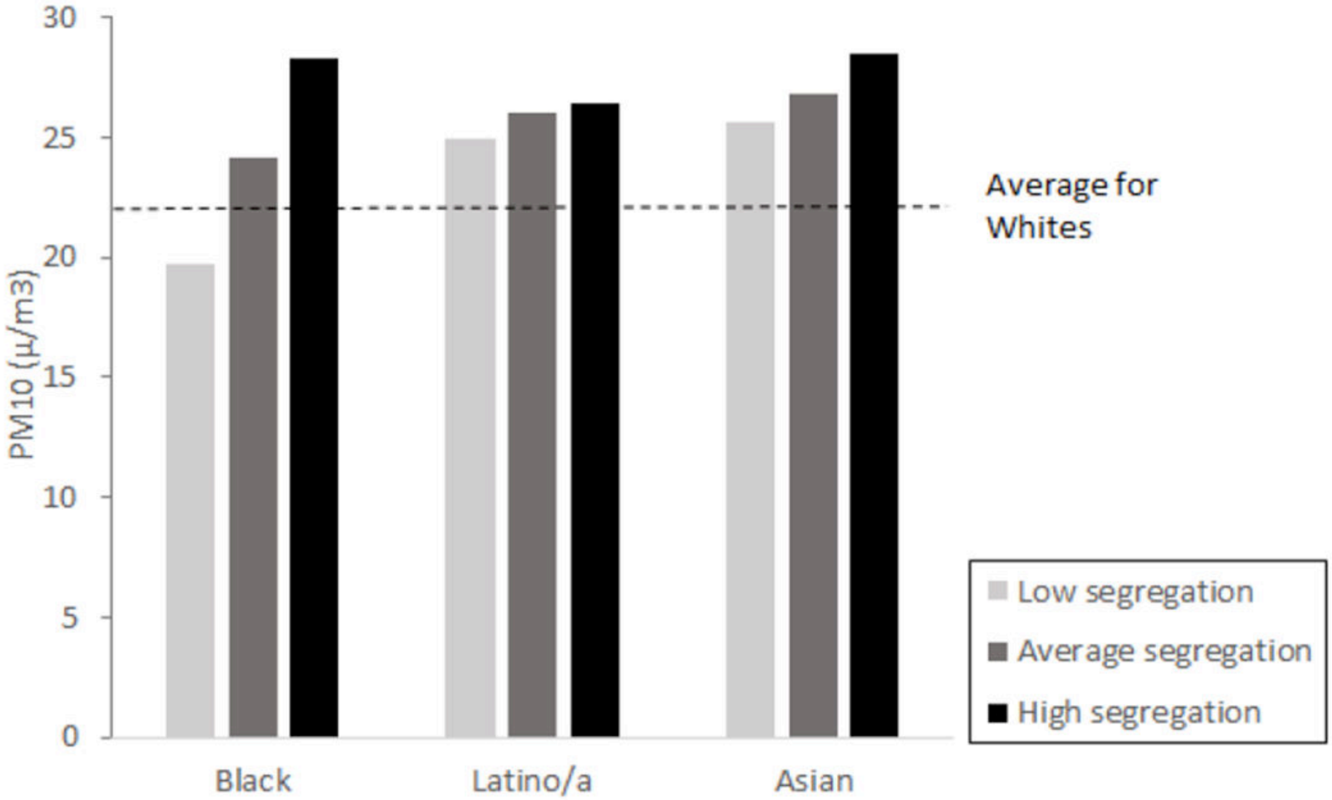

Figure 2. Racial/Ethnic Differences in the Neighborhood-Level PM_{10} Exposure by Different Levels of Residential Segregation

SOURCE Authors' analysis of data from the Panel Study of Income Dynamics (1990-2011), Environmental Protection Agency, and U.S. Census (1990-2010). **NOTES** Low segregation refers to the 10^{th} percentile of the dissimilarity index. High segregation refers to the 90^{th} percentile of the dissimilarity index.

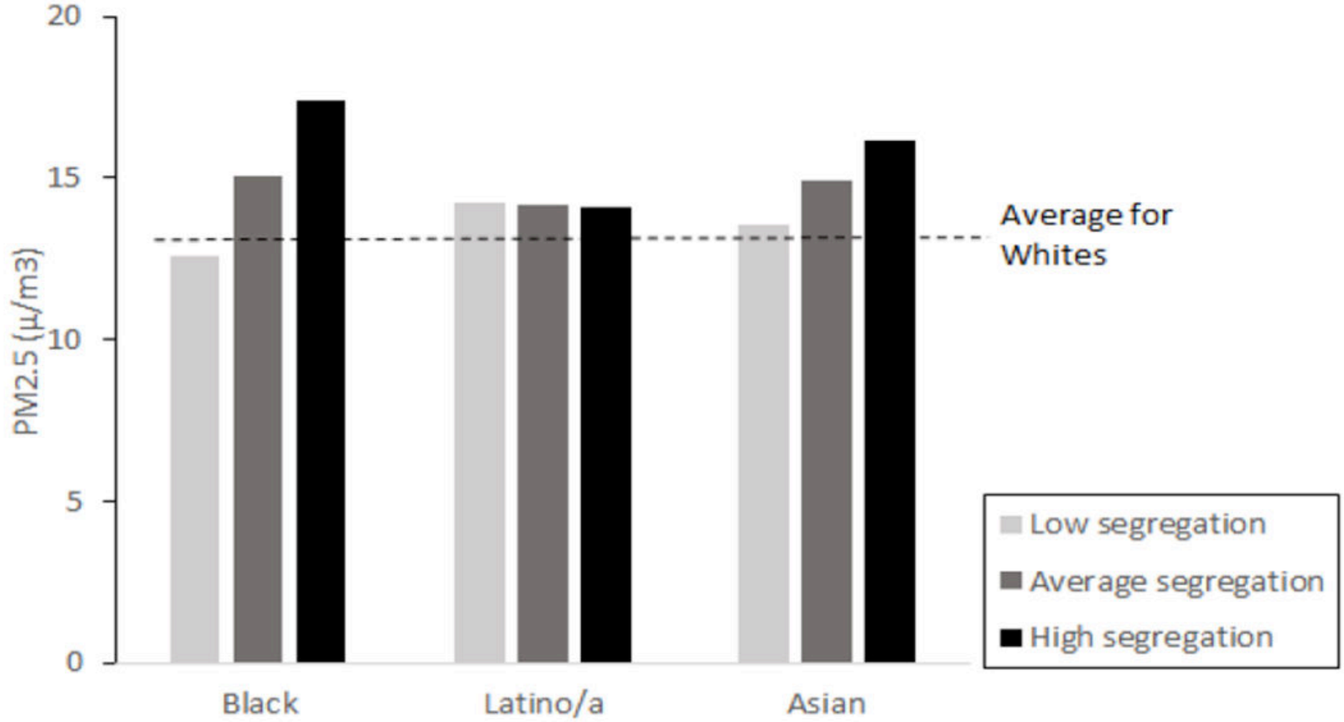

Figure 3. Neighborhood-Level $PM_{2.5}$ Exposure by Different Levels of Residential Segregation

SOURCE Authors' analysis of data from the Panel Study of Income Dynamics (1990-2011), Environmental Protection Agency, and U.S. Census (1990-2010). **NOTES** Low segregation refers to the 10^{th} percentile of the dissimilarity index. High segregation refers to the 90^{th} percentile of the dissimilarity index.

Table 1.

The Association between Race/Ethnicity and Residential Segregation and the Exposure to Three Types of Air Pollutants (N=19,299 person-periods)

	Coefficient (95% Confidence Interval)								
	NO_2			PM_{10}			$PM_{2.5}$		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Race/Ethnicity									
White (reference)									
Black	3.53** (3.17, 3.90)	3.35** (3.04, 3.65)	−7.04** (−8.37, −5.70)	2.08** (1.80, 2.37)	1.92** (1.66, 2.18)	−4.96** (−6.09, −3.83)	2.12** (1.95, 2.28)	1.94** (1.80, 2.09)	1.07** (.40, 1.74)
Latino/a	5.65** (4.69, 6.62)	4.30** (3.48, 5.12)	−11.8** (−15.05, −8.57)	4.53** (3.79, 5.27)	4.62** (3.85, 5.38)	−1.07 (−4.01, 1.88)	1.47** (1.09, 1.85)	1.61** (1.24, 1.97)	−1.61* (−3.09, −.13)
Asian	3.42** (2.24, 4.61)	4.58** (3.55, 5.61)	−1.64 (−5.41, 2.13)	3.04** (1.75, 4.32)	4.16** (2.85, 5.47)	.75 (−3.58, 5.08)	.29 (−.26, .85)	1.57** (1.10, 2.04)	−.62 (−2.31, 1.07)
Segregation from Whites									
Black segregation		11.92** (11.34, 12.50)	10.93** (10.34, 11.51)		10.96** (10.37, 11.56)	10.30** (9.69, 10.92)		10.55** (10.25, 10.86)	10.47** (10.16, 10.79)
Latino/a segregation		12.14** (11.32, 12.96)	11.78** (10.96, 12.60)		−4.55** (−5.31, −3.79)	−4.64** (−5.39, −3.88)		−6.59** (−6.94, −6.24)	−6.67** (−7.02, −6.31)
Asian segregation		−1.5** (−2.51, −.39)	−1.72** (−2.78, −0.67)		1.99** (.87, 3.11)	1.91** (.79, 3.02)		7.28** (6.69, 7.87)	7.18** (6.59, 7.77)
Race/Ethnicity×Segregation									
Black×Segregation			16.71** (14.58, 18.83)			11.06** (9.22, 12.91)			1.40** (.34, 2.47)
Latino/a×Segregation			31.90** (25.45, 38.34)			11.27** (5.56, 16.97)			6.36** (3.50, 9.22)
Asian×Segregation			17.13** (6.44, 27.82)			9.36 (−.21, 18.92)			6.10** (1.42, 10.78)
Constant	14.09** (13.99, 14.19)	2.37** (1.88, 2.85)	3.22** (2.73, 3.72)	22.35** (22.27, 22.44)	16.80** (16.31, 17.29)	17.27** (16.77, 17.77)	13.13** (13.08, 13.18)	6.58** (6.36, 6.80)	6.71** (6.48, 6.93)
R-squared	.04	.23	.25	.02	.10	.11	.04	.30	.30

SOURCE Authors’ analysis of data from the Panel Study of Income Dynamics (1990 - 2011), Environmental Protection Agency, and U.S. Census (1990 - 2010). **NOTES** Model 1 tests the bivariate association between race/ethnicity and exposure to each air pollutant. Model 2 tests the independent influence of race/ethnicity and residential segregation on exposure to each air pollutant. Model 3 tests the joint influence of race/ethnicity and residential segregation of each racial/ethnic group from Whites on exposure to each air pollutant.

* $p<0.05$

** $p<0.01$