Who is healthy anyways? Varying definitions of health in reference populations and the contribution of measurable social determinants to racial disparities in lung function

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## Abstract

**RATIONALE:** Racialized populations disproportionately experience exposures that impair lung function. Race-neutral reference equations are intended to mitigate bias due to disproportionate exposures at the cost of reduced precision. However, it is unclear what proportion of racial gaps in lung function is due to social determinants of health (SDoH). Previous studies on the racial gap in lung function between White and Black Americans have attributed 35-39% of the gap in adults to sitting height, 3-8% to poverty, and 2-5% to education. In children, sitting height reportedly accounted for 42-53% of the racial gap, while diet and socio-economic accounted for 7-10% of the gap. We hypothesized that disproportionate impact of SDoH that are captured in NAHNES data could help explain a larger proportion of racial gaps in lung function than previously reported. Better quantifying the contribution of measurable social determinants to racial differences in lung function can inform the debate on the proper assessment of lung function impairment across racial groups.

**METHODS:** We defined a series of nested reference populations using data from NHANES 2007-2012 participants. Starting with non-smokers without respiratory symptoms or diagnoses, we sequentially excluded those with confirmed occupational exposure to dust/fumes, physical inactivity, maternal tobacco use, obesity, no home ownership, no insurance, lower education, and self-reported unhealthy diet. Across successive populations, we compared average age-, sex-, and height-adjusted differences in FEV1 and FVC between minority race and ethnicity groups and White adults (≥20) and youth (<20).

**RESULTS:** From the base reference population to the most restrictive, the number of included participants decreased from 8,802 to 1,921. The percentage of Black participants decreased from 13% to 7% in youth and 11% to 4% in adults. Mexican American participants decreased from 15% to 10% in youth and 10% to 3% in adults. Other-Hispanic participants decreased from 7% to 5% in youth and 6% to 3% in adults. The proportion of participants remained close to the reference population for Asian and other-multiracial participants. After excluding individuals with unfavorable SDoH, the gap between Black and White Americans in FEV1 and FVC reduced by 25% to 26% in children and youth, and by 26% to 19% in adults over 20. The racial gap between Asian and White Americans reduced by 7% to 13% in youth but increased by 14% to 11% in adults. Mexican Americans had slightly higher FEV1 and FVC than White Americans in the baseline population, and excluding those with unfavorable SDoH widened the gap by 0.09 L to 0.06 L in youth and 0.03 L to 0.03 L in adults.

**CONCLUSIONS:** The SDoH investigated herein disporportionately affected Black, Mexican American, and Other Hispanic populations, and explained a higher proportion of racial disparities in lung function than previously reported.

## Background

Racial disparities in lung function measurements have been documented since the late 18th century. Initially, pro-slavery scientists in the US weaponized differences in lung function to justify White supremacy [1]. Over time, this overtly racist misuse was replaced with the notion that racial differences in lung function were innate but benign, often attributed to anthropometric variations. In the 20th century and with the growing adoption of pre-employment spirometry as a test of fitness for certain workers, occupation standards in the US proposed race-based adjustment of spirometry results to prevent hiring discrimination against Black individuals [2]. Subsequently, in 2005, the American Thoracic Society (ATS) and the European Respiratory Society (ERS) recommended race-specific reference equations for interpreting pulmonary function tests in clinical settings [3].

In the past two decades, race-based lung function reference values have been widely used to guide diagnosis, assessment, and management of lung diseases, determine priority for lung transplantation, evaluate fitness for employment, and assess occupational health and insurance claims. However, there is increasing awareness of how these practices may perpetuate racial bias and exacerbate health disparities, especially considering the disproportionate environmental exposures faced by racialized populations [4]. Emerging literature indicates that Black individuals in the US may experience harmful environmental exposures that adversely affect lung growth and function [5]. Race-based normalization of lung function may overlook these issues, potentially leading to the underdiagnosis and inadequate treatment of respiratory diseases in underserved communities.

Spirometry reference equations are developed with data from “healthy” volunteers, who do not smoke, are asymptomatic, and have not been diagnosed with lung diseases [6, 7]. This broad definition could introduce bias, as the reference populations may reflect systemic differences in lung function across racial groups not necessarily because of biological factors but rather due to unequal environmental or social conditions.

The effects of social determinants of health (SDoH) on lung function have been recognized for decades. The 1991 ATS official statements on the interpretative strategies for lung function testing acknowledged the effects of environmental factors, smoking, indoor and outdoor air pollution, occupational exposures, built environment and socio-economic factors as the main sources of between-individual variability in lung function[8]. The statement also mentioned racial differences that persist after adjusting for age, height, smoking, air pollution, and altitude, and hypothesized that these differences may in part be due to body measurements, environmental differences, nutrition, physical activity, and socioeconomic factors [8]. A 1986 review of between-individual variation in forced vital capacity (FVC) attributed up to 30% of variation to biological sex, up to 30% to age, height, and weight, 10% to race, 3% to measurement error, and 27% to unexplained factors[9]. Our study focuses on whether the proportion of variability that was historically attributed to race can be explained by SDoH.

Our understanding of the contribution of environmental and social factors to racial differences in lung function remains limited. A 2022 systematic review found two representative studies in the US population[10], one focused on adults[11] and one on children[12]. The study on adults attributed 35-39% of the racial gap in lung function to sitting height, 2.5-7.5% to poverty, and 2.0-4.7% to education [11]. In children, sitting height accounted for 42-53% of the racial gap, while diet and socio-economic status accounted for 7-10% of the racial differences [12]. However, these studies were limited, as they only considered lung function disparities between Black and White individuals, evaluated a narrow set of SDoH (typically comprised of poverty index, BMI, education, employment, and household size), and used older US National Health and Nutrition Examination Survey (NHANES) III survey data (1988–1994).

Our study aims to determine if a more comprehensive set of SDoH in newer NHANES data can explain a larger proportion of lung function disparities. By considering varied definitions of “healthy” in reference populations, we assess the impact of SDoH on racial lung function disparities across different self-identified racial and ethnic groups. We have presented a preliminary version of these results in the 2024 European Respiratory Congress in Vienna [13].

## Methods

We used data from three cycles of NHANES (2007-2012) with appropriate sampling weights to account for complex survey design. We included individuals with baseline spirometry that either met or exceeded ATS collection standards. We defined 10 increasingly healthier reference populations. Starting from the base reference population of non-smokers with no diagnoses of lung diseases or respiratory symptoms, we sequentially excluded those with confirmed occupational exposures, physical inactivity, maternal smoking, obesity (defined as body-mass-index≥30), no home ownership, no insurance, lower education, and self-declared unhealthy diet.

Occupational exposure was defined as having ever been exposed to either mineral dusts, organic dusts, exhaust fumes, or other fumes at work. Individuals who did not have at least 10 minutes of vigorous or moderate activity in a typical week, either for work or recreationally, were considered physically inactive. Lower educated individuals were defined as adults 20 years of age and older with a high school or a GED degree or lower, and 6-19 years old who were neither in school nor on vacation from school. Individuals with self-declared their dietary health as either poor or fair were considered to have a unhealthy diet.

For each reference population, the racial gap was calculated as the average difference in forced expiratory volume in one second (FEV1) and FVC between Black and White populations adjusted by age, height, and sex in a linear regression. We evaluated the reduction in the racial gap separately for youth (<20 yrs) and adults (≥20 yrs). The distinction between adults and youth was dictated by how NHANES data is collected and structured; for example, the educational level variable is only available for those 20 years of age and older and school attendance is more applicable to children and youth. We conducted additional exploratory analysis to evaluate the contribution of different variables in explaining racial gaps in lung function. We repeated the main analysis separately for individuals who self-identified with different minority groups, including Non-Hispanic Asian (only available in NHANES 2011-2012), Mexican American, Other Hispanic, and Other, including multiracial.

In the sensitivity analyses, we evaluated the results separately for males and females and those born inside the US. We also evaluated the proportion of the racial gap in lung function that can be explained by poverty alone to see whether poverty can be a good proxy for SDoH. To examine the effects of our choice of SDoH to account for, we conducted a leave-one-out analysis, where we reproduced the results 9 times, each time leaving one of the SDoH out of the successively defined reference populations.

All data preparation and analysis was performed in R v4.4.2 using reproducible Quarto documents. A fully reproducible analysis code is publicly available at <https://github.com/aminadibi/who-is-healthy-anyways/>.

## Results

Of the 30,442 participants in NHANES 2007-2012, we included 17,032 participants who had high-quality spirometry. Excluding smokers and individuals with respiratory diagnoses or symptoms led to 8,802 participants, including 4,832 adults and 3,970 youths ([Figure 1](#fig-flowchart)). Participant flow across successive reference populations is provided in appendix ([Figure S1](#suppfig-flowrefs)). Characteristics of participants is summarized in [Table 1](#tbl-table1) .

From the base reference population to the most restrictive, the number of included participants decreased from 8,802 to 1921. The proportion of participants decreased from 13% to 7% for Black youth, from 11% to 4% for Black adults, from 15% to 10% for Mexican American youth, from 10% to 3% for Mexican American adults, from 7% to 5% for Other Hispanic youth, and from 6% to 3% for Other Hispanic adults ([Figure 3](#fig-racialgap)). The reduction in the proportion of participants after multiple exclusions based on SDoH confirms disproportionate impact of these factors on Black, Mexican American, and Other Hispanic populations in the US. The proportion of participants remained within 1% of the reference population for participants who identified as either Asian or other race, including multiracial.

In the baseline reference population, average FEV1 and FVC were 0.35 L and 0.42 L higher in White youth compared with Black youth, after adjusting for age, height, and biological sex at birth. For adults, the adjusted racial gap was 0.50 L for FEV1 and 0.69 for FVC. After excluding those with unfavourable SDoH, the racial gap in FEV1 and FVC was reduced by 25% and 26% in youth and by 26% and 19% in adults ([Figure 3](#fig-racialgap)).

Excluding individuals with various SDoH did not reduce the proportion of Asian individuals. In the baseline reference population, average FEV1 and FVC were 0.18 L and 0.31 L higher in White youth compared with Asian youth, after adjusting for age, height, and biological sex at birth. For adults, the adjusted racial gap was 0.37 L for FEV1 and 0.50 for FVC. After excluding those with unfavourable SDoH, the racial gap in FEV1 and FVC was reduced by 7% and 13% in youth but, surprisingly, increased by 14% and 11% in adults ([Figure S5](#suppfig-Asian)).

Mexican American youth had slightly higher FEV1 and FVC at baseline compared to White youth. Average FEV1 and FVC were 0.06 L and 0.04 L higher in Mexican American youth compared to White youth, after adjusting for age, height, and biological sex at birth. Mexican American and White adults had similar adjusted FEV1 and FVC at baseline ([Figure S6](#suppfig-Mexican)). Excluding individuals with unfavourable SDoH resulted in higher FEV1 and FVC values for Mexican American population compared to White population. Adjusted average FEV1 and FVC values for Mexican American youth were 0.09 L and 0.06 L higher than White youth. For adults, average FEV1 and FVC were both higher by 0.03 L compared to White adults ([Figure S6](#suppfig-Mexican)).

The appendix includes additional results for non-Mexican Hispanic population ([Figure S7](#suppfig-hispanic)) and other race including multiracial individuals ([Figure S8](#suppfig-Other)).

### Secondary and Sensitivity Analyses

We conducted a number of additional analyses for on lung function gap between Black and White populations.

#### Biological Sex

We also looked at the racial gap in lung function from the most permissive to the most restrictive reference population, separately for females and males. In females, the proportion of Black participants decreased from 20% to 10% in youth and 15% to 5% in adults. After excluding those with various social and environmental exposures, the racial gap in FEV1 and FVC was reduced by 16% and 19% in youth, and by 27% and 20% in adults, respectively (appendix [Figure S2](#suppfig-females)). In males, the proportion of Black participants decreased from 17% to 8% in youth and 12% to 4% in adults. After excluding those with various social and environmental exposures, the racial gap in FEV1 and FVC was reduced by 35% and 34% in youth and by 14% and 8% in adults (appendix [Figure S3](#suppfig-males)).

#### Home Ownership, BMI, and Occupation

After excluding patients solely based on home ownership, BMI, and occupation, the proportion of Black participants decreased from 19% to 10% in youth and 14% to 11% in adults, as shown in [Figure 4](#fig-racialgap-home-bmi-job). Limiting reference populations to non-obese homeowners without occupational exposures to dusts and fumes reduced the racial gap in FEV1 and FVC by 21% and 19% in youth and 20% and 16% in adults.

#### Country of Birth

We also explored the intersection of self-identified race and country of birth. After excluding those with various social and environmental exposures, the racial gap in FEV1 and FVC was reduced by 24% and 25% in US-born youth, and by 35% and 23% in US-born adults ([Figure S4](#suppfig-usborn)). Black and White individuals born outside of the US had higher FEV1 and FVC, were less exposed to second-hand and maternal smoking, had healthier diets, but also had more occupational exposures ([Table S2](#supptab-fig1byusborn)). Black individuals born out of the US had higher income and were more likely to be covered by health insurance than US-born Black individuals while among White participants, those who were born in the US had higher income and higher insurance coverage ([Table S2](#supptab-fig1byusborn)).

#### Leave-one-out Analysis

In the leave-one-out analysis for the youth, the proportion of racial gap explained by SDoH remained consistent at 25% for FEV1 and 26% for FVC. In the leave-one-out analysis for adults, the proportion of racial gap explained by SDoH was consistently 26% for FEV1 and 19% for FVC, except for when diet health was not accounted for, in which case the proportion of racial gaps explained by SDoH was 29% for FEV1 and 18% for FVC. Further details are provided in the supplement ([Figure S10](#suppfig-leavejob) to [Figure S18](#suppfig-leavediet)).

## Discussion

Our results show that a higher than previously reported proportion of racial differences in lung function between Black and White Americans can be explained by differences in SDoH [11, 12]. Within studied SDoH variables in NHANES 2007-2012, we were able to explain 26% of the racial gap in lung function in adults, and as much as 35% of the gap in males under 20 years of age. The true contribution of SDoH to racial gaps in lung function is likely higher, as only some aspects of SDoH are properly captured in NHANES. The difficulty of measuring SDoH and our incomplete and evolving understanding of the complex interplay between racism, social, and environmental factors suggest that what we see might just be the tip of the iceberg.

Our results are consistent with a growing body of literature that implicates historical and structural inequities in perpetuating health disparities among racialized communities [14–17]. However, considerable variability exists within race categories. We observed a higher explained proportion of the racial gap in lung function among US-born Black and White individuals (i.e., up to 36% of the racial gap in adult FEV1 explained by the studied exposures). This might be related to US-specific systemic factors such as the enduring impact of slavery, segregation, redlining, and other inequities and injustices may have a more pronounced effect on lung health for those born in the US. This is supported by studies reporting significantly higher levels of allostatic load, hypertension, and mortality risk among US-born self-identified Black individuals compared to Black immigrants [18–20] and among Black people born in different parts of the US [21]. It is important to note that many immigrants may arrive at a young age and experience prolonged exposure to these same systemic factors; however, the generational effects and specific historical context faced by US-born individuals could lead to distinct health outcomes observed at an aggregate level.

Our exploratory analysis also revealed that occupational exposures, obesity, and non-home ownership were the three exclusion criteria most responsible for explaining the racial gap in lung function between Black and White individuals.

Similar to the reference populations used to develop lung function reference equations, our baseline reference population only excluded individuals with a history of smoking, lung disease, or respiratory symptoms. In this population, age-, sex-, and height-adjusted FEV1 and FVC were highest for Mexican Americans, followed by Non-Hispanic White, Other Hispanic, Asian, and Non-Hispanic Black populations. Introducing nine additional exclusion criteria to reference populations reduced racial disparities in lung function between Black and White individuals, but not for Asian population. Of note, the proportion of Asian people in the successive reference populations remained within 1% of the baseline value, indicating that the investigated SDoH did not disproportionately affect this population.

What are the implications for lung function reference equations? Since these equations are designed to predict healthy lung function, they need to make an assumption about the nature of racial gaps in lung function, either explicitly or implicitly. For decades, ATS lung function testing guidelines have acknowledged the effects of social and environmental factors on the variability of lung function across populations [8]. However, race-specific lung function reference equations implicitly assumed racial gaps in lung function were normal and benign, the same way that differences based on biological sex at birth, height, and age, were considered normal. This practice was at odds with the recognized role of SDoH, reinforced inequities not just by perpetuating the notion of race as a biological determinant, but also by failing to account for the fact that at least some of the observed racial gap may be pathological, due to injury or suboptimal development caused by SDoH. In 2023, the ATS statement on race and ethnicity in pulmonary function testing advocated for a significant shift in practice. The statement acknowledged the importance and complexity of these exposures, rejected fixed differences between races, and embraced a more uncertain race-averaged reference equation, instead of the misleading statistical accuracy of the previous race-based equations [22].

The newly recommended race-averaged GLI-Global reference equations no longer assume that racial differences in lung function are normal and benign differences. However, do they assume these differences are solely due to disproportionate environmental exposures and SDoH? The answer seems to be no, as GLI-Global equations use averages of four race-specific reference lung function projections, as opposed to projecting the highest race-specific value for all [7].

Developing unbiased, fair, and practical lung function reference equations is challenging because of our limited understanding of complex exposures, lack of good representative data, and diverse applications of pulmonary function tests [23, 24]. Recognizing the good faith efforts of those working diligently to find a balance between feasibility, practicality, and an ideal accounting for all potential biases, one potential way forward, at least for some use cases of spirometry, involves explicitly accounting for effect of complex exposures. This does not require asking patients for their exposure history or social determinants at the point of care and can be achieved by tightening the inclusion criteria in the reference populations at the reference algorithm development stage. Excluding individuals with unfavourable SDoH from reference populations results in a more uniformly healthy reference population across racial identities and makes the dataset less biased. However, this approach may reduce the racial representativeness of the data due to disproportionate exposures. Ensuring a sufficiently large and representative initial sample may allow oversampling to achieve representativeness across all groups.

Proposals for developing lung function standards using data from participants of “middle-class origin who live and work in clean environments” have appeared in the literature as early as 1984 [25]. There is also precedence for choosing reference populations based on favourable SDoH outside of lung function testing. One prominent example is the World Health Organization (WHO) Multicentre Growth Reference Study that was conducted to create birth to 2-years growth standards [26]. The study’s sites were chosen through a meticulous process that took into account geographical and ethnic representativeness, and included affluent communities in the cities of New Delhi and Accra, as well as participants from Muscat, Oslo, Davis, and Pelotas. The eligibility criteria for individual mother and children included no health, environmental, and economic constraints on growth, mother’s willingness to follow WHO feeding recommendations, among others [26].

Our study highlights the necessity for further research to understand the interplay between SDoH, environmental exposures, and lung function across different populations. Future studies should aim to incorporate a wider array of SDoH, such as stress levels, neighborhood safety, and intergenerational effects, including those related to wealth, social status, poverty, and trauma. There is also a need for longitudinal studies that can elucidate the emergence of lung function disparities (as has been done in childhood asthma[27]), associated causal pathways ,and the potential impact of policy changes on reducing health disparities. Exploring the intersectionality of race and other demographic factors could provide a more nuanced understanding of how diverse identities influence lung health outcomes. Expanding research to include international cohorts with high quality data collection could enhance the generalizability of findings and support the development of global and localized strategies to address lung health disparities.

Certain limitations must be acknowledged. Our reliance on NHANES data restricts generalizability beyond the United States and hinders our ability to explore nuanced race and ethnicity groups. We were not able to assess potential role of altitude and anthropometric differences, including those related to torso and leg length due to unavailability of the data in the studied NHANES cycles. Incomplete understanding and limited nature of available data also limits our assessment of complex social and environmental exposures and identities, such as effects of racism, intergenerational effects, life-course exposure to pollutants, gender identity, stress, and allostatic load.

## Conclusions

Our study underscores the significant influence of social determinants of health on lung function and shows that a larger proportion of racial gaps in lung function can be explained by social determinants of health than previously reported. However, we were unable to account for all racial differences in lung function based on measured social determinants of health in NHANES 2007-2012.

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| Figure 1: Flow of participants |

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| Table 1: Characteristics of Participants Included in the Baseline Reference Population   |  | Adults (N=4832) | Youth (N=3970) | Overall (N=8802) | | --- | --- | --- | --- | | **Age (years)** |  |  |  | | Mean (SD) | 45 (16) | 12 (3.8) | 30 (20) | | Median [Min, Max] | 43 [20, 79] | 11 [6.0, 19] | 23 [6.0, 79] | | **Race and Ethnicity** |  |  |  | | Mexican American | 928 (19.2%) | 1055 (26.6%) | 1983 (22.5%) | | Non-Hispanic Asian | 328 (6.8%) | 186 (4.7%) | 514 (5.8%) | | Non-Hispanic Black | 968 (20.0%) | 921 (23.2%) | 1889 (21.5%) | | Non-Hispanic White | 1817 (37.6%) | 1137 (28.6%) | 2954 (33.6%) | | Other Hispanic | 567 (11.7%) | 467 (11.8%) | 1034 (11.7%) | | Other Race - Including Multi-Racial | 224 (4.6%) | 204 (5.1%) | 428 (4.9%) | | **Biological Sex at Birth** |  |  |  | | Female | 2772 (57.4%) | 2016 (50.8%) | 4788 (54.4%) | | Male | 2060 (42.6%) | 1954 (49.2%) | 4014 (45.6%) | | **FEV1 (L)** |  |  |  | | Mean (SD) | 3.1 (0.85) | 2.6 (0.98) | 2.9 (0.95) | | Median [Min, Max] | 3.1 [0.51, 6.9] | 2.4 [0.82, 6.1] | 2.8 [0.51, 6.9] | | **FVC (L)** |  |  |  | | Mean (SD) | 3.9 (1.0) | 3.0 (1.1) | 3.5 (1.2) | | Median [Min, Max] | 3.8 [0.70, 7.9] | 2.8 [0.96, 7.2] | 3.4 [0.70, 7.9] | | **Smoker in household** |  |  |  | | No | 4592 (95.0%) | 3474 (87.5%) | 8066 (91.6%) | | Yes | 220 (4.6%) | 477 (12.0%) | 697 (7.9%) | | Missing | 20 (0.4%) | 19 (0.5%) | 39 (0.4%) | | **Maternal smoke during pregnancy (For youth)** |  |  |  | | No | 0 (0%) | 2673 (67.3%) | 2673 (30.4%) | | Yes | 0 (0%) | 333 (8.4%) | 333 (3.8%) | | Missing | 4832 (100%) | 964 (24.3%) | 5796 (65.8%) | | **Occupational Exposure to Mineral Dusts** |  |  |  | | No | 3486 (72.1%) | 415 (10.5%) | 3901 (44.3%) | | Yes | 1124 (23.3%) | 101 (2.5%) | 1225 (13.9%) | | Missing | 222 (4.6%) | 3454 (87.0%) | 3676 (41.8%) | | **Occupational Exposure to Organic Dusts** |  |  |  | | No | 3821 (79.1%) | 411 (10.4%) | 4232 (48.1%) | | Yes | 789 (16.3%) | 105 (2.6%) | 894 (10.2%) | | Missing | 222 (4.6%) | 3454 (87.0%) | 3676 (41.8%) | | **Occupational Exposure to Exhaust Fumes** |  |  |  | | No | 3814 (78.9%) | 468 (11.8%) | 4282 (48.6%) | | Yes | 799 (16.5%) | 48 (1.2%) | 847 (9.6%) | | Missing | 219 (4.5%) | 3454 (87.0%) | 3673 (41.7%) | | **Occupational Exposure to Other Fumes** |  |  |  | | No | 3485 (72.1%) | 420 (10.6%) | 3905 (44.4%) | | Yes | 1128 (23.3%) | 96 (2.4%) | 1224 (13.9%) | | Missing | 219 (4.5%) | 3454 (87.0%) | 3673 (41.7%) | | **Income to Poverty Ratio** |  |  |  | | Mean (SD) | 2.8 (1.7) | 2.1 (1.6) | 2.5 (1.7) | | Median [Min, Max] | 2.6 [0, 5.0] | 1.6 [0, 5.0] | 2.1 [0, 5.0] | | Missing | 445 (9.2%) | 332 (8.4%) | 777 (8.8%) | | **Home Owner** |  |  |  | | Yes | 29 (0.6%) | 27 (0.7%) | 56 (0.6%) | | No | 4803 (99.4%) | 3943 (99.3%) | 8746 (99.4%) | | **Health Insurance** |  |  |  | | Don't Know | 1 (0.0%) | 12 (0.3%) | 13 (0.1%) | | No | 1200 (24.8%) | 550 (13.9%) | 1750 (19.9%) | | Refused | 1 (0.0%) | 3 (0.1%) | 4 (0.0%) | | Yes | 3629 (75.1%) | 3405 (85.8%) | 7034 (79.9%) | | Missing | 1 (0.0%) | 0 (0%) | 1 (0.0%) | | **Education Level for Adults** |  |  |  | | College graduate or above | 1495 (30.9%) | 0 (0%) | 1495 (17.0%) | | Some college or AA degree | 1382 (28.6%) | 0 (0%) | 1382 (15.7%) | | High school graduate | 930 (19.2%) | 0 (0%) | 930 (10.6%) | | 9-11th grade | 543 (11.2%) | 0 (0%) | 543 (6.2%) | | Less than 9th grade | 476 (9.9%) | 0 (0%) | 476 (5.4%) | | Missing | 6 (0.1%) | 3970 (100%) | 3976 (45.2%) | | **Currently Attending School (for youth)** |  |  |  | | Between grades | 0 (0%) | 429 (10.8%) | 429 (4.9%) | | In school | 0 (0%) | 1928 (48.6%) | 1928 (21.9%) | | Missing | 4832 (100%) | 1613 (40.6%) | 6445 (73.2%) | | **Self-evaluated Diet Health** |  |  |  | | Excellent | 456 (9.4%) | 68 (1.7%) | 524 (6.0%) | | Very good | 1068 (22.1%) | 174 (4.4%) | 1242 (14.1%) | | Good | 2133 (44.1%) | 428 (10.8%) | 2561 (29.1%) | | Fair | 996 (20.6%) | 208 (5.2%) | 1204 (13.7%) | | Poor | 176 (3.6%) | 42 (1.1%) | 218 (2.5%) | | Missing | 3 (0.1%) | 3050 (76.8%) | 3053 (34.7%) | | **Vigorous Activity at Work (10 min/week)** |  |  |  | | No | 4040 (83.6%) | 1765 (44.5%) | 5805 (66.0%) | | Yes | 792 (16.4%) | 165 (4.2%) | 957 (10.9%) | | Missing | 0 (0%) | 2040 (51.4%) | 2040 (23.2%) | | **Moderate Activity at Work (10 min/week)** |  |  |  | | No | 3119 (64.5%) | 1316 (33.1%) | 4435 (50.4%) | | Yes | 1713 (35.5%) | 614 (15.5%) | 2327 (26.4%) | | Missing | 0 (0%) | 2040 (51.4%) | 2040 (23.2%) | | **Recreational Vigorous Activity (10 min/week)** |  |  |  | | No | 3468 (71.8%) | 766 (19.3%) | 4234 (48.1%) | | Yes | 1364 (28.2%) | 1164 (29.3%) | 2528 (28.7%) | | Missing | 0 (0%) | 2040 (51.4%) | 2040 (23.2%) | | **Recreational Moderate Activity (10 min/week)** |  |  |  | | No | 2681 (55.5%) | 986 (24.8%) | 3667 (41.7%) | | Yes | 2151 (44.5%) | 944 (23.8%) | 3095 (35.2%) | | Missing | 0 (0%) | 2040 (51.4%) | 2040 (23.2%) | | **Body Mass Index** |  |  |  | | Mean (SD) | 29 (6.4) | 21 (5.7) | 25 (7.1) | | Median [Min, Max] | 28 [15, 73] | 20 [13, 54] | 25 [13, 73] | | Missing | 15 (0.3%) | 23 (0.6%) | 38 (0.4%) | |

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| Figure 2: Changes in population composition in successively more restrictive reference populations. Each reference population adds additional exclusion criteria based on social determinants of health. Race and ethnicity groups that experience a decline in their percentage of the population compared to the reference baseline (moving from left to right) are disproportionately affected by the harmful social determinants of health that are being considered here. |

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| Figure 3: Changes in lung function racial gaps between Non-Hispanic Black and Non-Hispanic White participants in successively more restrictive reference populations. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

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| Figure 4: Changes in lung function racial gaps between Non-Hispanic Black and Non-Hispanic White participants after exclusions based on home ownership, BMI, and occupational exposures to fumes and dusts. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

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## Appendices

### Participant Flow Across Successive Reference Populations

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| Flow of participants across different reference populations    Figure S1 |

### Participants Characteristics by Race

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| |  | Mexican American (N=1983) | Non-Hispanic Asian (N=514) | Non-Hispanic Black (N=1889) | Non-Hispanic White (N=2954) | Other Hispanic (N=1034) | Other Race - Including Multi-Racial (N=428) | Overall (N=8802) | | --- | --- | --- | --- | --- | --- | --- | --- | | **Age (years)** |  |  |  |  |  |  |  | | Mean (SD) | 26 (18) | 31 (19) | 29 (20) | 33 (21) | 30 (20) | 27 (18) | 30 (20) | | Median [Min, Max] | 18 [6.0, 79] | 27 [6.0, 79] | 20 [6.0, 79] | 30 [6.0, 79] | 24 [6.0, 78] | 21 [6.0, 75] | 23 [6.0, 79] | | **Race and Ethnicity** |  |  |  |  |  |  |  | | Mexican American | 1983 (100%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 1983 (22.5%) | | Non-Hispanic Asian | 0 (0%) | 514 (100%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 514 (5.8%) | | Non-Hispanic Black | 0 (0%) | 0 (0%) | 1889 (100%) | 0 (0%) | 0 (0%) | 0 (0%) | 1889 (21.5%) | | Non-Hispanic White | 0 (0%) | 0 (0%) | 0 (0%) | 2954 (100%) | 0 (0%) | 0 (0%) | 2954 (33.6%) | | Other Hispanic | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 1034 (100%) | 0 (0%) | 1034 (11.7%) | | Other Race - Including Multi-Racial | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 428 (100%) | 428 (4.9%) | | **Biological Sex at Birth** |  |  |  |  |  |  |  | | Female | 1057 (53.3%) | 292 (56.8%) | 1078 (57.1%) | 1554 (52.6%) | 581 (56.2%) | 226 (52.8%) | 4788 (54.4%) | | Male | 926 (46.7%) | 222 (43.2%) | 811 (42.9%) | 1400 (47.4%) | 453 (43.8%) | 202 (47.2%) | 4014 (45.6%) | | **FEV1 (L)** |  |  |  |  |  |  |  | | Mean (SD) | 2.9 (0.91) | 2.7 (0.85) | 2.7 (0.87) | 3.1 (1.0) | 2.8 (0.92) | 2.8 (0.97) | 2.9 (0.95) | | Median [Min, Max] | 2.9 [0.95, 5.8] | 2.7 [0.51, 5.8] | 2.6 [0.82, 5.6] | 3.1 [0.90, 6.9] | 2.8 [0.89, 5.8] | 2.8 [0.79, 5.3] | 2.8 [0.51, 6.9] | | **FVC (L)** |  |  |  |  |  |  |  | | Mean (SD) | 3.4 (1.1) | 3.2 (1.0) | 3.2 (1.0) | 3.8 (1.3) | 3.4 (1.1) | 3.4 (1.2) | 3.5 (1.2) | | Median [Min, Max] | 3.4 [1.2, 7.0] | 3.2 [0.70, 6.7] | 3.1 [1.0, 7.0] | 3.8 [1.0, 7.9] | 3.3 [1.1, 7.4] | 3.4 [1.0, 6.6] | 3.4 [0.70, 7.9] | | **Birth Country** |  |  |  |  |  |  |  | | Don't know | 1 (0.1%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (0.0%) | | Other countries | 776 (39.1%) | 339 (66.0%) | 194 (10.3%) | 150 (5.1%) | 540 (52.2%) | 170 (39.7%) | 2169 (24.6%) | | Refused | 4 (0.2%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (0.1%) | 1 (0.2%) | 6 (0.1%) | | US | 1202 (60.6%) | 175 (34.0%) | 1695 (89.7%) | 2804 (94.9%) | 493 (47.7%) | 257 (60.0%) | 6626 (75.3%) | | **Smoker in household** |  |  |  |  |  |  |  | | No | 1881 (94.9%) | 498 (96.9%) | 1633 (86.4%) | 2670 (90.4%) | 983 (95.1%) | 401 (93.7%) | 8066 (91.6%) | | Yes | 94 (4.7%) | 14 (2.7%) | 246 (13.0%) | 275 (9.3%) | 42 (4.1%) | 26 (6.1%) | 697 (7.9%) | | Missing | 8 (0.4%) | 2 (0.4%) | 10 (0.5%) | 9 (0.3%) | 9 (0.9%) | 1 (0.2%) | 39 (0.4%) | | **Maternal smoke during pregnancy (For youth)** |  |  |  |  |  |  |  | | No | 797 (40.2%) | 117 (22.8%) | 580 (30.7%) | 700 (23.7%) | 339 (32.8%) | 140 (32.7%) | 2673 (30.4%) | | Yes | 32 (1.6%) | 6 (1.2%) | 71 (3.8%) | 189 (6.4%) | 17 (1.6%) | 18 (4.2%) | 333 (3.8%) | | Missing | 1154 (58.2%) | 391 (76.1%) | 1238 (65.5%) | 2065 (69.9%) | 678 (65.6%) | 270 (63.1%) | 5796 (65.8%) | | **Occupational Exposure to Mineral Dusts** |  |  |  |  |  |  |  | | No | 684 (34.5%) | 292 (56.8%) | 845 (44.7%) | 1454 (49.2%) | 437 (42.3%) | 189 (44.2%) | 3901 (44.3%) | | Yes | 291 (14.7%) | 27 (5.3%) | 238 (12.6%) | 489 (16.6%) | 132 (12.8%) | 48 (11.2%) | 1225 (13.9%) | | Missing | 1008 (50.8%) | 195 (37.9%) | 806 (42.7%) | 1011 (34.2%) | 465 (45.0%) | 191 (44.6%) | 3676 (41.8%) | | **Occupational Exposure to Organic Dusts** |  |  |  |  |  |  |  | | No | 761 (38.4%) | 292 (56.8%) | 946 (50.1%) | 1541 (52.2%) | 489 (47.3%) | 203 (47.4%) | 4232 (48.1%) | | Yes | 212 (10.7%) | 27 (5.3%) | 138 (7.3%) | 403 (13.6%) | 80 (7.7%) | 34 (7.9%) | 894 (10.2%) | | Missing | 1010 (50.9%) | 195 (37.9%) | 805 (42.6%) | 1010 (34.2%) | 465 (45.0%) | 191 (44.6%) | 3676 (41.8%) | | **Occupational Exposure to Exhaust Fumes** |  |  |  |  |  |  |  | | No | 832 (42.0%) | 301 (58.6%) | 880 (46.6%) | 1570 (53.1%) | 494 (47.8%) | 205 (47.9%) | 4282 (48.6%) | | Yes | 143 (7.2%) | 18 (3.5%) | 204 (10.8%) | 375 (12.7%) | 75 (7.3%) | 32 (7.5%) | 847 (9.6%) | | Missing | 1008 (50.8%) | 195 (37.9%) | 805 (42.6%) | 1009 (34.2%) | 465 (45.0%) | 191 (44.6%) | 3673 (41.7%) | | **Occupational Exposure to Other Fumes** |  |  |  |  |  |  |  | | No | 710 (35.8%) | 279 (54.3%) | 855 (45.3%) | 1439 (48.7%) | 437 (42.3%) | 185 (43.2%) | 3905 (44.4%) | | Yes | 265 (13.4%) | 40 (7.8%) | 229 (12.1%) | 506 (17.1%) | 132 (12.8%) | 52 (12.1%) | 1224 (13.9%) | | Missing | 1008 (50.8%) | 195 (37.9%) | 805 (42.6%) | 1009 (34.2%) | 465 (45.0%) | 191 (44.6%) | 3673 (41.7%) | | **Income to Poverty Ratio** |  |  |  |  |  |  |  | | Mean (SD) | 1.7 (1.3) | 3.1 (1.7) | 2.3 (1.6) | 3.1 (1.7) | 2.0 (1.5) | 2.7 (1.7) | 2.5 (1.7) | | Median [Min, Max] | 1.3 [0, 5.0] | 3.2 [0, 5.0] | 1.9 [0, 5.0] | 3.3 [0, 5.0] | 1.6 [0, 5.0] | 2.2 [0, 5.0] | 2.1 [0, 5.0] | | Missing | 237 (12.0%) | 59 (11.5%) | 163 (8.6%) | 140 (4.7%) | 133 (12.9%) | 45 (10.5%) | 777 (8.8%) | | **Home Owner** |  |  |  |  |  |  |  | | Yes | 19 (1.0%) | 5 (1.0%) | 12 (0.6%) | 9 (0.3%) | 9 (0.9%) | 2 (0.5%) | 56 (0.6%) | | No | 1964 (99.0%) | 509 (99.0%) | 1877 (99.4%) | 2945 (99.7%) | 1025 (99.1%) | 426 (99.5%) | 8746 (99.4%) | | **Health Insurance** |  |  |  |  |  |  |  | | Don't Know | 4 (0.2%) | 1 (0.2%) | 7 (0.4%) | 1 (0.0%) | 0 (0%) | 0 (0%) | 13 (0.1%) | | No | 726 (36.6%) | 71 (13.8%) | 294 (15.6%) | 297 (10.1%) | 284 (27.5%) | 78 (18.2%) | 1750 (19.9%) | | Refused | 3 (0.2%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (0.2%) | 4 (0.0%) | | Yes | 1250 (63.0%) | 442 (86.0%) | 1588 (84.1%) | 2656 (89.9%) | 750 (72.5%) | 348 (81.3%) | 7034 (79.9%) | | Missing | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (0.2%) | 1 (0.0%) | | **Education Level for Adults** |  |  |  |  |  |  |  | | College graduate or above | 96 (4.8%) | 178 (34.6%) | 247 (13.1%) | 764 (25.9%) | 95 (9.2%) | 115 (26.9%) | 1495 (17.0%) | | Some college or AA degree | 202 (10.2%) | 72 (14.0%) | 355 (18.8%) | 560 (19.0%) | 142 (13.7%) | 51 (11.9%) | 1382 (15.7%) | | High school graduate | 170 (8.6%) | 40 (7.8%) | 222 (11.8%) | 341 (11.5%) | 126 (12.2%) | 31 (7.2%) | 930 (10.6%) | | 9-11th grade | 188 (9.5%) | 20 (3.9%) | 119 (6.3%) | 119 (4.0%) | 84 (8.1%) | 13 (3.0%) | 543 (6.2%) | | Less than 9th grade | 271 (13.7%) | 18 (3.5%) | 25 (1.3%) | 31 (1.0%) | 119 (11.5%) | 12 (2.8%) | 476 (5.4%) | | Missing | 1056 (53.3%) | 186 (36.2%) | 921 (48.8%) | 1139 (38.6%) | 468 (45.3%) | 206 (48.1%) | 3976 (45.2%) | | **Currently Attending School (for youth)** |  |  |  |  |  |  |  | | Between grades | 52 (2.6%) | 0 (0%) | 91 (4.8%) | 219 (7.4%) | 37 (3.6%) | 30 (7.0%) | 429 (4.9%) | | In school | 625 (31.5%) | 0 (0%) | 425 (22.5%) | 542 (18.3%) | 240 (23.2%) | 96 (22.4%) | 1928 (21.9%) | | Missing | 1306 (65.9%) | 514 (100%) | 1373 (72.7%) | 2193 (74.2%) | 757 (73.2%) | 302 (70.6%) | 6445 (73.2%) | | **Self-evaluated Diet Health** |  |  |  |  |  |  |  | | Excellent | 63 (3.2%) | 53 (10.3%) | 121 (6.4%) | 214 (7.2%) | 47 (4.5%) | 26 (6.1%) | 524 (6.0%) | | Very good | 147 (7.4%) | 120 (23.3%) | 217 (11.5%) | 559 (18.9%) | 128 (12.4%) | 71 (16.6%) | 1242 (14.1%) | | Good | 520 (26.2%) | 167 (32.5%) | 521 (27.6%) | 914 (30.9%) | 312 (30.2%) | 127 (29.7%) | 2561 (29.1%) | | Fair | 369 (18.6%) | 36 (7.0%) | 290 (15.4%) | 312 (10.6%) | 160 (15.5%) | 37 (8.6%) | 1204 (13.7%) | | Poor | 55 (2.8%) | 6 (1.2%) | 74 (3.9%) | 57 (1.9%) | 20 (1.9%) | 6 (1.4%) | 218 (2.5%) | | Missing | 829 (41.8%) | 132 (25.7%) | 666 (35.3%) | 898 (30.4%) | 367 (35.5%) | 161 (37.6%) | 3053 (34.7%) | | **Vigorous Activity at Work (10 min/week)** |  |  |  |  |  |  |  | | No | 1224 (61.7%) | 409 (79.6%) | 1275 (67.5%) | 1930 (65.3%) | 687 (66.4%) | 280 (65.4%) | 5805 (66.0%) | | Yes | 195 (9.8%) | 27 (5.3%) | 175 (9.3%) | 422 (14.3%) | 99 (9.6%) | 39 (9.1%) | 957 (10.9%) | | Missing | 564 (28.4%) | 78 (15.2%) | 439 (23.2%) | 602 (20.4%) | 248 (24.0%) | 109 (25.5%) | 2040 (23.2%) | | **Moderate Activity at Work (10 min/week)** |  |  |  |  |  |  |  | | No | 951 (48.0%) | 343 (66.7%) | 1003 (53.1%) | 1370 (46.4%) | 549 (53.1%) | 219 (51.2%) | 4435 (50.4%) | | Yes | 468 (23.6%) | 93 (18.1%) | 447 (23.7%) | 982 (33.2%) | 237 (22.9%) | 100 (23.4%) | 2327 (26.4%) | | Missing | 564 (28.4%) | 78 (15.2%) | 439 (23.2%) | 602 (20.4%) | 248 (24.0%) | 109 (25.5%) | 2040 (23.2%) | | **Recreational Vigorous Activity (10 min/week)** |  |  |  |  |  |  |  | | No | 910 (45.9%) | 269 (52.3%) | 902 (47.8%) | 1442 (48.8%) | 539 (52.1%) | 172 (40.2%) | 4234 (48.1%) | | Yes | 509 (25.7%) | 167 (32.5%) | 548 (29.0%) | 910 (30.8%) | 247 (23.9%) | 147 (34.3%) | 2528 (28.7%) | | Missing | 564 (28.4%) | 78 (15.2%) | 439 (23.2%) | 602 (20.4%) | 248 (24.0%) | 109 (25.5%) | 2040 (23.2%) | | **Recreational Moderate Activity (10 min/week)** |  |  |  |  |  |  |  | | No | 904 (45.6%) | 216 (42.0%) | 852 (45.1%) | 1041 (35.2%) | 490 (47.4%) | 164 (38.3%) | 3667 (41.7%) | | Yes | 515 (26.0%) | 220 (42.8%) | 598 (31.7%) | 1311 (44.4%) | 296 (28.6%) | 155 (36.2%) | 3095 (35.2%) | | Missing | 564 (28.4%) | 78 (15.2%) | 439 (23.2%) | 602 (20.4%) | 248 (24.0%) | 109 (25.5%) | 2040 (23.2%) | | **Body Mass Index** |  |  |  |  |  |  |  | | Mean (SD) | 25 (6.8) | 23 (4.8) | 27 (8.1) | 26 (7.2) | 25 (6.6) | 23 (6.1) | 25 (7.1) | | Median [Min, Max] | 25 [13, 54] | 22 [13, 43] | 26 [13, 69] | 25 [13, 73] | 25 [13, 53] | 23 [13, 52] | 25 [13, 73] | | Missing | 7 (0.4%) | 3 (0.6%) | 13 (0.7%) | 10 (0.3%) | 3 (0.3%) | 2 (0.5%) | 38 (0.4%) |   Table S1: Characteristics of Participants Included in the Baseline Reference Population by Self-identified Race |

### Separate Analysis by Biological Sex

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| Figure S2: Changes in lung function racial gaps between female Non-Hispanic Black and Non-Hispanic White participants in successively more restrictive reference populations solely based on income to poverty ratio. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

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| Figure S3: Changes in lung function racial gaps between male Non-Hispanic Black and Non-Hispanic White participants in successively more restrictive reference populations solely based on income to poverty ratio. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

### Intersection of Race and Country of Birth

We produced results separately for self-identified Black and White person born in the US.

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| Figure S4: Racial gap in lung function among those born in the US |

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| |  | Other countries | | US | | Overall | | | --- | --- | --- | --- | --- | --- | --- | |  | Non-Hispanic Black (N=194) | Non-Hispanic White (N=150) | Non-Hispanic Black (N=1695) | Non-Hispanic White (N=2804) | Non-Hispanic Black (N=1889) | Non-Hispanic White (N=2954) | | **Age (years)** |  |  |  |  |  |  | | Mean (SD) | 40 (17) | 40 (22) | 28 (20) | 33 (21) | 29 (20) | 33 (21) | | Median [Min, Max] | 41 [6.0, 79] | 38 [6.0, 79] | 19 [6.0, 79] | 29 [6.0, 79] | 20 [6.0, 79] | 30 [6.0, 79] | | **Race and Ethnicity** |  |  |  |  |  |  | | Non-Hispanic Black | 194 (100%) | 0 (0%) | 1695 (100%) | 0 (0%) | 1889 (100%) | 0 (0%) | | Non-Hispanic White | 0 (0%) | 150 (100%) | 0 (0%) | 2804 (100%) | 0 (0%) | 2954 (100%) | | **Biological Sex at Birth** |  |  |  |  |  |  | | Female | 93 (47.9%) | 87 (58.0%) | 985 (58.1%) | 1467 (52.3%) | 1078 (57.1%) | 1554 (52.6%) | | Male | 101 (52.1%) | 63 (42.0%) | 710 (41.9%) | 1337 (47.7%) | 811 (42.9%) | 1400 (47.4%) | | **FEV1 (L)** |  |  |  |  |  |  | | Mean (SD) | 2.8 (0.80) | 3.2 (0.97) | 2.7 (0.88) | 3.1 (1.0) | 2.7 (0.87) | 3.1 (1.0) | | Median [Min, Max] | 2.7 [0.82, 5.0] | 3.1 [1.2, 6.1] | 2.6 [0.82, 5.6] | 3.1 [0.90, 6.9] | 2.6 [0.82, 5.6] | 3.1 [0.90, 6.9] | | **FVC (L)** |  |  |  |  |  |  | | Mean (SD) | 3.4 (0.96) | 3.9 (1.2) | 3.2 (1.1) | 3.8 (1.3) | 3.2 (1.0) | 3.8 (1.3) | | Median [Min, Max] | 3.3 [1.1, 6.0] | 3.9 [1.4, 7.0] | 3.1 [1.0, 7.0] | 3.8 [1.0, 7.9] | 3.1 [1.0, 7.0] | 3.8 [1.0, 7.9] | | **Smoker in household** |  |  |  |  |  |  | | No | 191 (98.5%) | 145 (96.7%) | 1442 (85.1%) | 2525 (90.1%) | 1633 (86.4%) | 2670 (90.4%) | | Yes | 3 (1.5%) | 5 (3.3%) | 243 (14.3%) | 270 (9.6%) | 246 (13.0%) | 275 (9.3%) | | Missing | 0 (0%) | 0 (0%) | 10 (0.6%) | 9 (0.3%) | 10 (0.5%) | 9 (0.3%) | | **Maternal smoke during pregnancy (For youth)** |  |  |  |  |  |  | | No | 18 (9.3%) | 23 (15.3%) | 562 (33.2%) | 677 (24.1%) | 580 (30.7%) | 700 (23.7%) | | Yes | 0 (0%) | 1 (0.7%) | 71 (4.2%) | 188 (6.7%) | 71 (3.8%) | 189 (6.4%) | | Missing | 176 (90.7%) | 126 (84.0%) | 1062 (62.7%) | 1939 (69.2%) | 1238 (65.5%) | 2065 (69.9%) | | **Occupational Exposure to Mineral Dusts** |  |  |  |  |  |  | | No | 136 (70.1%) | 98 (65.3%) | 709 (41.8%) | 1356 (48.4%) | 845 (44.7%) | 1454 (49.2%) | | Yes | 30 (15.5%) | 18 (12.0%) | 208 (12.3%) | 471 (16.8%) | 238 (12.6%) | 489 (16.6%) | | Missing | 28 (14.4%) | 34 (22.7%) | 778 (45.9%) | 977 (34.8%) | 806 (42.7%) | 1011 (34.2%) | | **Occupational Exposure to Organic Dusts** |  |  |  |  |  |  | | No | 153 (78.9%) | 98 (65.3%) | 793 (46.8%) | 1443 (51.5%) | 946 (50.1%) | 1541 (52.2%) | | Yes | 13 (6.7%) | 18 (12.0%) | 125 (7.4%) | 385 (13.7%) | 138 (7.3%) | 403 (13.6%) | | Missing | 28 (14.4%) | 34 (22.7%) | 777 (45.8%) | 976 (34.8%) | 805 (42.6%) | 1010 (34.2%) | | **Occupational Exposure to Exhaust Fumes** |  |  |  |  |  |  | | No | 137 (70.6%) | 107 (71.3%) | 743 (43.8%) | 1463 (52.2%) | 880 (46.6%) | 1570 (53.1%) | | Yes | 29 (14.9%) | 9 (6.0%) | 175 (10.3%) | 366 (13.1%) | 204 (10.8%) | 375 (12.7%) | | Missing | 28 (14.4%) | 34 (22.7%) | 777 (45.8%) | 975 (34.8%) | 805 (42.6%) | 1009 (34.2%) | | **Occupational Exposure to Other Fumes** |  |  |  |  |  |  | | No | 130 (67.0%) | 88 (58.7%) | 725 (42.8%) | 1351 (48.2%) | 855 (45.3%) | 1439 (48.7%) | | Yes | 36 (18.6%) | 28 (18.7%) | 193 (11.4%) | 478 (17.0%) | 229 (12.1%) | 506 (17.1%) | | Missing | 28 (14.4%) | 34 (22.7%) | 777 (45.8%) | 975 (34.8%) | 805 (42.6%) | 1009 (34.2%) | | **Income to Poverty Ratio** |  |  |  |  |  |  | | Mean (SD) | 2.7 (1.5) | 3.1 (1.8) | 2.2 (1.6) | 3.1 (1.7) | 2.3 (1.6) | 3.1 (1.7) | | Median [Min, Max] | 2.4 [0, 5.0] | 3.1 [0, 5.0] | 1.8 [0, 5.0] | 3.3 [0, 5.0] | 1.9 [0, 5.0] | 3.3 [0, 5.0] | | Missing | 15 (7.7%) | 15 (10.0%) | 148 (8.7%) | 125 (4.5%) | 163 (8.6%) | 140 (4.7%) | | **Home Owner** |  |  |  |  |  |  | | Yes | 0 (0%) | 0 (0%) | 12 (0.7%) | 9 (0.3%) | 12 (0.6%) | 9 (0.3%) | | No | 194 (100%) | 150 (100%) | 1683 (99.3%) | 2795 (99.7%) | 1877 (99.4%) | 2945 (99.7%) | | **Health Insurance** |  |  |  |  |  |  | | No | 51 (26.3%) | 22 (14.7%) | 243 (14.3%) | 275 (9.8%) | 294 (15.6%) | 297 (10.1%) | | Yes | 143 (73.7%) | 128 (85.3%) | 1445 (85.3%) | 2528 (90.2%) | 1588 (84.1%) | 2656 (89.9%) | | Don't Know | 0 (0%) | 0 (0%) | 7 (0.4%) | 1 (0.0%) | 7 (0.4%) | 1 (0.0%) | | **Education Level for Adults** |  |  |  |  |  |  | | College graduate or above | 58 (29.9%) | 60 (40.0%) | 189 (11.2%) | 704 (25.1%) | 247 (13.1%) | 764 (25.9%) | | Some college or AA degree | 58 (29.9%) | 22 (14.7%) | 297 (17.5%) | 538 (19.2%) | 355 (18.8%) | 560 (19.0%) | | High school graduate | 23 (11.9%) | 15 (10.0%) | 199 (11.7%) | 326 (11.6%) | 222 (11.8%) | 341 (11.5%) | | 9-11th grade | 17 (8.8%) | 7 (4.7%) | 102 (6.0%) | 112 (4.0%) | 119 (6.3%) | 119 (4.0%) | | Less than 9th grade | 6 (3.1%) | 9 (6.0%) | 19 (1.1%) | 22 (0.8%) | 25 (1.3%) | 31 (1.0%) | | Missing | 32 (16.5%) | 37 (24.7%) | 889 (52.4%) | 1102 (39.3%) | 921 (48.8%) | 1139 (38.6%) | | **Currently Attending School (for youth)** |  |  |  |  |  |  | | Between grades | 1 (0.5%) | 11 (7.3%) | 90 (5.3%) | 208 (7.4%) | 91 (4.8%) | 219 (7.4%) | | In school | 11 (5.7%) | 14 (9.3%) | 414 (24.4%) | 528 (18.8%) | 425 (22.5%) | 542 (18.3%) | | Missing | 182 (93.8%) | 125 (83.3%) | 1191 (70.3%) | 2068 (73.8%) | 1373 (72.7%) | 2193 (74.2%) | | **Self-evaluated Diet Health** |  |  |  |  |  |  | | Excellent | 31 (16.0%) | 26 (17.3%) | 90 (5.3%) | 188 (6.7%) | 121 (6.4%) | 214 (7.2%) | | Very good | 38 (19.6%) | 40 (26.7%) | 179 (10.6%) | 519 (18.5%) | 217 (11.5%) | 559 (18.9%) | | Good | 78 (40.2%) | 46 (30.7%) | 443 (26.1%) | 868 (31.0%) | 521 (27.6%) | 914 (30.9%) | | Fair | 23 (11.9%) | 10 (6.7%) | 267 (15.8%) | 302 (10.8%) | 290 (15.4%) | 312 (10.6%) | | Poor | 6 (3.1%) | 2 (1.3%) | 68 (4.0%) | 55 (2.0%) | 74 (3.9%) | 57 (1.9%) | | Missing | 18 (9.3%) | 26 (17.3%) | 648 (38.2%) | 872 (31.1%) | 666 (35.3%) | 898 (30.4%) | | **Vigorous Activity at Work (10 min/week)** |  |  |  |  |  |  | | No | 157 (80.9%) | 122 (81.3%) | 1118 (66.0%) | 1808 (64.5%) | 1275 (67.5%) | 1930 (65.3%) | | Yes | 27 (13.9%) | 14 (9.3%) | 148 (8.7%) | 408 (14.6%) | 175 (9.3%) | 422 (14.3%) | | Missing | 10 (5.2%) | 14 (9.3%) | 429 (25.3%) | 588 (21.0%) | 439 (23.2%) | 602 (20.4%) | | **Moderate Activity at Work (10 min/week)** |  |  |  |  |  |  | | No | 130 (67.0%) | 98 (65.3%) | 873 (51.5%) | 1272 (45.4%) | 1003 (53.1%) | 1370 (46.4%) | | Yes | 54 (27.8%) | 38 (25.3%) | 393 (23.2%) | 944 (33.7%) | 447 (23.7%) | 982 (33.2%) | | Missing | 10 (5.2%) | 14 (9.3%) | 429 (25.3%) | 588 (21.0%) | 439 (23.2%) | 602 (20.4%) | | **Recreational Vigorous Activity (10 min/week)** |  |  |  |  |  |  | | No | 126 (64.9%) | 89 (59.3%) | 776 (45.8%) | 1353 (48.3%) | 902 (47.8%) | 1442 (48.8%) | | Yes | 58 (29.9%) | 47 (31.3%) | 490 (28.9%) | 863 (30.8%) | 548 (29.0%) | 910 (30.8%) | | Missing | 10 (5.2%) | 14 (9.3%) | 429 (25.3%) | 588 (21.0%) | 439 (23.2%) | 602 (20.4%) | | **Recreational Moderate Activity (10 min/week)** |  |  |  |  |  |  | | No | 110 (56.7%) | 60 (40.0%) | 742 (43.8%) | 981 (35.0%) | 852 (45.1%) | 1041 (35.2%) | | Yes | 74 (38.1%) | 76 (50.7%) | 524 (30.9%) | 1235 (44.0%) | 598 (31.7%) | 1311 (44.4%) | | Missing | 10 (5.2%) | 14 (9.3%) | 429 (25.3%) | 588 (21.0%) | 439 (23.2%) | 602 (20.4%) | | **Body Mass Index** |  |  |  |  |  |  | | Mean (SD) | 27 (6.0) | 26 (6.9) | 27 (8.3) | 25 (7.2) | 27 (8.1) | 26 (7.2) | | Median [Min, Max] | 27 [15, 50] | 25 [14, 54] | 25 [13, 69] | 25 [13, 73] | 26 [13, 69] | 25 [13, 73] | | Missing | 1 (0.5%) | 0 (0%) | 12 (0.7%) | 10 (0.4%) | 13 (0.7%) | 10 (0.3%) |   Table S2: Characteristics of Black Participants Included in the Baseline Reference Population by Country of Birth |

### Other Race Groups

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| Figure S5: Changes in lung function racial gaps between Asian and Non-Hispanic White participants in successively more restrictive reference populations. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

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| Mexican American vs. White    Figure S6: Changes in lung function racial gaps between Mexican American and Non-Hispanic White participants in successively more restrictive reference populations. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. Negative values indicated higher lung function in the Mexican American population. |

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| Figure S7: Changes in lung function racial gaps between Other Hispanic and Non-Hispanic White participants in successively more restrictive reference populations. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

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| Figure S8: Changes in lung function racial gaps between Other race including multi-racial and Non-Hispanic White participants in successively more restrictive reference populations. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

### Income to Poverty Ratio

When we excluded participants with income to poverty ratio under five, the proportion of Black participants decreased from 19% to 10% in youth and 14% to 8% in adults, as shown in [Figure S9](#suppfig-incomepovertyratio). The proportion of racial gap in FEV1 and FVC that was explained by poverty was 6% and 0% in adults, and 4% and 2% in youth.

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| Figure S9: Changes in lung function racial gaps between Non-Hispanic Black and Non-Hispanic White participants in successively more restrictive reference populations solely based on income to poverty ratio. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population. |

### Leave-one-out Analysis

Changes in lung function racial gaps between Non-Hispanic Black and Non-Hispanic White participants in successively more restrictive reference populations. In each of the figures below, one of the original SDoH-based exclusion criteria are left out. Lung function differences are adjusted for height, age, and biological sex at birth. Positive values indicate higher lung function in the Non-Hispanic White population.

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| Figure S10: Leaving out job exposure |

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| Figure S11: Leaving out physical activity |

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| Figure S12: Leaving out maternal smoke |

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| Figure S13: Leaving out second-hand smoke exposure |

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| Figure S14: Leaving out obesity |

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| Figure S15: Leaving out homeownership |

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| Figure S16: Leaving out health insurance |

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| Figure S17: Leaving out education |

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| Figure S18: Leaving out diet health |