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Racial Disparities in Allergic Outcomes Persist to Age 10 Years in Black and White Children

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Abstract

Background: Previous analyses in the WHEALS birth cohort demonstrated black children are more likely to experience allergic outcomes than white children by age 2 years. The results could not be explained by a host of variables.

Objective: Assess whether racial disparities persisted to age 10 years and determine whether any differences could be explained by a panel of variables related to early life exposures in WHEALS.

Methods: At age 10 years, WHEALS children (n=481) completed skin prick testing, spirometry and methacholine challenge and a physician exam for eczema and asthma. Allergen-specific IgEs (sIgE) and total IgE were measured. Inverse probability weighting with logistic and linear regression models was used to assess associations between race (black or white) and the outcomes.

Results: Black children fared worse than white children with respect to each outcome. Black children were more likely to have eczema, asthma, sensitization (≥1 sIgE≥0.35 IU/L) and at least one positive skin pick test; however, some variability was present in the magnitudes of association within subgroups defined by delivery mode, sex of the child, prenatal indoor dog exposure, and firstborn status. In some subgroups, Black children were also more likely to have higher total IgE and worse pulmonary function test measures (PC 20 ≤25 mg/ml, % predicted FVC, FEV1/FVC, FEF 25–75). Confounding did not explain these differences.

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Conclusion: Racial differences persisted in this cohort through age 10 years. Future studies should include potentially important, but rarely studied factors such as segregation and structural racism as these factors could explain the observed racial differences.

Introduction

In our previous work, we reported that Black children were more likely to experience allergic outcomes by age 2 years when compared with White children in the WHEALS birth cohort from the Detroit, Michigan, USA area.(1, 2) Black children were more likely than white children to have had atopic dermatitis, at least one positive skin prick test, and at least one elevated allergen-specific IgE (sIgE≥0.35IU/L). Black children also tended to have higher total IgE compared with white children. These disparities persisted even after adjusting for a panel of potential confounders including maternal education, household income and pet keeping. Children in Detroit, a city with predominantly Black residents, have one of the highest rates of asthma in the country and the highest in the state of Michigan. Black children have a 50% higher hospital admission rate for asthma compared to white children in Michigan.(3)

Others have reported similar findings related to racial disparities in allergy and asthma outcomes.(4–6) In a cohort study based in Boston, they found that Black children were more likely to have atopic dermatitis (AD) and have AD that persisted compared with White children.(4) Eczema was more common in Black children compared with other children 17 years of age and under in the National Survey of Children's Health.(6) In these studies, racial differences persisted even after adjusting for factors related to socioeconomic status (SES). Black individuals were more likely to have at least one positive skin prick test compared with White individuals in NHANES III.(7) In National Health Interview Survey 1997–2003 and 2001–2016 data, Black children had the highest rates of asthma among children <18 years of age.(8, 9) These national studies tended to have fewer variables for adjustments. These previous studies are limited by use of questionnaire data to assess some outcomes and/or small sample sizes of Black children.

Together, these results have not yet led to actionable prevention strategies to reduce racial disparities. In these studies, even after adjusting for SES-related variables such as income and education, disparities persisted. These results suggest that aspects of SES do not fully explain these disparities and other causes are yet to be identified.

WHEALS is a birth cohort whose mothers were not recruited based on parental history of allergic diseases. The majority of WHEALS participants are Black providing opportunity to consider effect modification within race subgroups. The children of WHEALS completed study-specific clinic visits at approximately age 10 years. The goal of the present analyses was to assess whether the observed racial disparities persisted, as well as identify any racial differences in lung function measures. We also examined whether any observed differences varied within subgroups or could be explained by any measured risk factors, including those associated with socioeconomic status (SES).

Methods

Children who participated in the WHEALS birth cohort were invited for a study-specific clinic visit at age 10 years.(10) Written informed consent was obtained from their parent or guardian for participation in this IRB (#1881) approved study. At the clinic visit, children completed spirometry with methacholine challenge (MC), had skin prick testing performed, and completed a blood draw to measure total and allergen-specific IgE (sIgE). The children also met with a physician for a physical examination, which included an evaluation for eczema. The parent also completed an interview and questionnaire about the child's health history.

Child's race was based on maternal report for her child at age 2 years. We are including only those children who are Black/African American and White/Non-Hispanic/Non-Middle Eastern to examine racial disparities. The subgroups of children who are White/Hispanic or White/Middle Eastern may have different risks for the outcomes and are too few in number to analyze as subgroups.(11) For these analyses, the following outcomes were examined at child age approximately 10 years:

- Total IgE (log-transformed for normality)
- Sensitized to at least one sIgE (sIgE≥0.35 IU/L out of a panel of 10 food and inhalant allergens: dog, cat, cockroach, *Dermatophagoides farinae*, common ragweed, timothy grass, mold mixture, hen's egg, cow's milk and peanut)
- Skin prick test positive (diameter of wheal ≥3mm greater than the saline control to at least one allergen from a panel of 19 food and inhalant allergens: *Alternaria tenuis*, *Aspergillus fumigatus*, *Hormodendrum cladosporioides*, *Penicillium notatum*, cat, cockroach mix, mouse, rat, short ragweed, timothy grass, birch mix, oak (red), hen's egg, cow's milk, peanut, soybean, wheat, codfish, shrimp)
- Atopic dermatitis (eczema) at the time of the clinic visit based on physician assessment
- Current Asthma, based on physician assessment which included spirometry, MC results, skin prick testing results and a clinical examination
- Percent predicted Forced Expiratory Volume at 1 second (FEV_1 % predicted adjusted for age and race)
- Percent predicted Forced Vital Capacity (FVC % predicted) (adjusted for race)
- FEV_1/FVC ratio (adjusted for race)
- Percent predicted Forced Expiratory Flow from 25% to 75% of Vital Capacity (FEF25–75 % predicted) (adjusted for race)
- Methacholine Dose at which FEV_1 dropped by 20% from baseline (provocation concentration=PC_{20}) was less than or equal to the maximum dose (PC_{20}≤25 mg/ml). (methacholine doses administered: diluent only, 0.098 mg/ml, 0.195 mg/ml, 0.391 mg/ml, 0.781 mg/ml, 1.563 mg/ml, 3.125 mg/ml, 6.25 mg/ml, 12.5 mg/ml, 25.0 mg/ml)

Skin prick testing and sIgE measurement were both performed as they may provide different information.(12, 13) The children were asked to complete methacholine challenge (MC) in accordance with ATS/ATS Preschool Guidelines and the methacholine doses were the same as those used by the Inner City Asthma Consortium (ICAC) for the URECA Birth Cohort. (14–16) If the baseline (pre-diluent) FEV_1 was less than 70% predicted and/or the child was unable to perform acceptable and repeatable spirometry, then MC was not performed. Any child who was actively wheezing when they entered the clinic was asked to perform spirometry but not MC, and skin prick testing was not conducted. The dose causing the 20% drop in FEV1 from baseline was recorded as the provocation concentration (PC_{20}).

Additional variables considered in the analyses (baseline covariates, confounders, and effect modifiers) were taken from maternal interview responses or maternal prenatal medical chart review. These variables included: number of older siblings, maternal prenatal household income, prenatal maternal education, whether mother made monthly mortgage or rental payments during pregnancy, mother lived with indoor pets (dogs and cats) during pregnancy, maternal marital status during pregnancy, whether the child was ever breastfed, prenatal environmental tobacco smoke exposure, parental history of doctor-diagnosed allergies, birthweight z-score, gestational age at birth, maternal use of systemic prenatal antibiotics or antifungal medications, maternal BMI in pregnancy, season of birth, maternal age at delivery, sex of child, and delivery mode. We were unable to adjust for urban vs. rural residence due to extremely high correlation: in our analysis subset, 27% of black children lived in a suburban setting, compared to 94% of white children. However, location of residence was used as a baseline covariate to assess loss to follow-up. Additionally, some variables were also assessed for effect modification (delivery mode, child ever breastfed, child was firstborn, sex of child, and mother lived with an indoor dog in pregnancy).

Not all children who enrolled in WHEALS participated in the age 10-year clinic visit. Children included and excluded from analyses were first compared across a wide range of baseline covariates using standard parametric statistics. Standardized differences were used to quantify effect sizes of differences, with imbalance defined as absolute value greater than 0.20. To account for potential bias due to loss to follow-up, inverse probability weights (IPWs) were calculated (among the black and white children only) using the covariates shown in Table 1, with “included or excluded” used as the binary outcome in a logistic regression model. The inverse probability of inclusion was used as a weight in all analyses, with weights normalized to sum to the actual sample size.

Logistic regression models were used for all binary outcomes, while linear regression was used for all continuous outcomes. Total IgE at age 10 was log-transformed prior to analysis to normalize residuals; no other continuous outcomes required transformation. Within the analysis subset, there is still some missingness in outcomes and adjustment covariates. Each outcome was first assessed using “complete-case” analysis in both unadjusted and adjusted models. These estimates were then followed by pooled estimates using multiple imputation. A total of 20 imputed datasets were created using the FCS method in “proc mi” (SAS), with all exposure variables, outcome variables, confounders, and effect modifiers included. Imputation performance was assessed through trace plots and variance information. Imputed estimates were pooled using “proc mianalyze”. For all analyses, significance of main effects

was pre-specified at p-value<0.05, while significance of interaction effects was pre-specified at p-value<0.10 to allow examination of patterns that would not achieve p<0.05 due to decreased sample sizes in these subgroup analyses.

Results

Of the 1,053 black or white children enrolled in WHEALS, 481 had information on at least one of the specified 10-year outcomes. Among these 481 children, the average age at the 10-year clinic visit was 10.3 (SD=0.8, Min=8.6, Max=13.6). Among the black and white children in WHEALS, we first compared those included versus excluded from analyses (Table 1). Prior to inverse probability weighting, children included in the analysis had mothers who were older, had higher household incomes and higher levels of education, were more likely to be married and have health insurance, and were less likely to be exposed to environmental tobacco smoke (ETS) prenatally (all p<0.05). Additionally, on average, children included in the analysis had higher birthweight z-scores and had fewer older siblings (both p<0.05). Effect sizes of these statistically significant differences were often large, with the absolute value of standardized differences ranging from 0.14 to 0.68 (where >0.20 is considered imbalanced). However, following IPW, these imbalances were no longer present, as no differences in covariates between those included and excluded from the analyses reached statistical significance (all p≥0.42), and the maximum absolute standardized difference was 0.04, suggesting the IPW had performed well in achieving bias reduction due to loss to follow up.

In unadjusted analyses of binary outcomes (Table 2), black children were more likely to be sensitized to ≥1 sIgE (odds ratio=OR=1.9, 95% CI 1.2, 2.9), have eczema (OR=2.9, 95%CI 1.5, 5.8), and have asthma (OR=4.8, 95% CI 2.2, 10.3) than white children. This was not true for being skin prick test positive (OR=1.28, 95%CI 0.82, 1.99) or having had PC_{20}≤ 25 mg/ml (OR=1.3, 95% CI 0.82, 2.0). When models were fully-adjusted for all potential confounders in complete-case analyses (i.e., without imputation), some standard errors and effect sizes were very large, due to small sample sizes. However, fully-adjusted imputation models provided more precise estimates. Though there were some fluctuations in effect sizes, conclusions about associations largely remained the same, except for having PC_{20}≤25 mg/ml. Specifically, after imputation and full covariate adjustment, black children were more likely to have PC_{20}≤25 mg/ml compared with white children (OR=2.1, 95% CI 1.2, 3.9). Models adjusting for each covariate individually (using complete-case analysis) are also provided to enable an understanding of which covariates are associated with the largest shifts in effect sizes.

Effect modification was then evaluated for these binary outcomes in the fully-adjusted imputation models (Table 3) using interaction terms. Of the variables examined, prenatal indoor dog exposure modified the association between race and atopy (interaction p<0.05), child's firstborn status modified the association between race and having a skin prick test positive test (interaction p=0.095) and sex of the child modified the association between race and having PC_{20}≤25 mg/ml (interaction p=0.091). Although imprecise due to the sample size, among children whose mother lived with an indoor dog during pregnancy, black children were more likely to be sensitized to ≥1 sIgE than white children (OR=11.2, 95% CI

3.3, 37.4); race was not associated with sIgE sensitization among children whose mothers did not live with a dog during pregnancy. Among those firstborn, black children were more likely to have a positive skin prick test (OR=1.7, 95% CI 0.5, 5.8); however, among those not firstborn black children were less likely to have a positive test (OR=0.7, 95% CI 0.3, 1.9). Among males, black children were more likely to have PC_{20}≤25 mg/ml (OR=3.5, 95% CI 1.5, 8.0) but among females, black children were not more likely to have PC_{20}≤25 mg/ml (OR=1.1, 95% CI 0.4, 3.1).

In unadjusted analyses of continuous outcome variables (Table 4), only the association between race and total IgE reached statistical significance. The geometric mean of total IgE was 86% higher for black children compared with white children (β=0.62, SE=0.16, exp(0.62)=1.86). Spirometry outcome variables did not differ between Black and White children. However, after fully adjusting for all covariates in the imputation model, the difference in total IgE between black and white children was reduced and no longer statistically significant (β=0.25, SE=0.21, exp(0.25)=1.28). However, percent predicted FVC at age 10 was statistically significantly higher in Black children compared with White children in the fully adjusted imputation model (β=4.08, SE=1.87, p=0.03).

When effect modification of these associations was examined (Table 5), several associations were reviewed. Mode of delivery was a statistically significant effect modifier of the associations between race and the outcomes of total IgE, the FEV_1/FVC ratio and percent predicted FEF 25–75. Within children born via C-section, black children had an 99% increase in geometric mean of total IgE at age 10, compared with white children (β=0.69, SE=0.35, exp(0.69)=1.99; p=0.049); no important differences between black children and white children were found within vaginally delivered children (β= −0.02, SE=0.27, exp(−0.02)=0.98). A similar pattern was found for FEV_1/FVC: within children born via C-section, black children had a decrease in the ratio compared with white children (β=−4.3, SE=0.1.89; p=0.02); no important differences between black children and white children were found within vaginally delivered children (β= −0.33, SE=1.36, exp(−0.02)=0.81). Interestingly, among children born via C-section, black children had had lower percent predicted FEF 25–75 compared with white children (β=−9.51, SE=6.62, p=0.15) but among vaginally delivered children, black children had higher percent predicted FEF 25–75 (β=7.43, SE=5.24, p=0.16). Finally, among children born to a woman who lived with a dog during pregnancy, black children tended to have higher total IgE (β= 0.73, SE=0.38, exp(0.73)=2.08); this was not true for children whose mothers did not live with a dog during pregnancy (β= −0.20, SE=0.28, exp(−0.20)=0.82).

Discussion

These data from WHEALS suggest that even after adjusting for many SES and other lifestyle variables, black children generally fared worse than white children with respect to allergic and lung function outcomes. These outcomes included eczema, asthma, and having PC_{20}≤25 mg/ml during methacholine challenge at age 10. There was variability of some associations within subgroups defined by birth order, delivery mode and prenatal maternal dog exposure and the outcomes of sensitization to ≥1 sIgE, skin prick testing, lung function measures and total IgE. These subgroup differences, which are rarely investigated in asthma

and allergy studies, highlight the importance of examining effect modification rather than solely adjusting for potential confounders in epidemiological studies.

Other studies have also documented these racial disparities. In the Project Viva birth cohort, Black children were more likely to have atopic dermatitis in early childhood (adjusted OR=2.71, 95% CI 1.75, 4.19).(4) Data from the 2003 National Survey on Children's Health of children 17 years of age and younger suggest that Black race was associated with an increased odds of having a diagnosis of eczema in the past 12 months (OR=1.70, $p<0.05$).(6) Black individuals were more likely to have at least one positive skin prick test compared with White individuals in NHANES III (adjusted OR=1.6, 95% CI 1.4, 1.9).(7) Black children had higher rates of asthma among children <18 years of age in both the National Health Interview Survey 1997–2003 data and the 2001–2016 data.(8, 9) These national studies tended to have fewer variables for adjustments. No study focused on racial disparities within subgroups defined by factors such as birth order and delivery mode.

There are likely many interrelated factors that underpin these disparities such as variation in frequency of disease endotypes, unmeasured exposures including toxicants and non-toxicants, and genetics. Only recently have consortiums been able to amass enough sample size to conduct genetic studies of black individuals. In recent work, the Consortium on Asthma among African Ancestry Populations (CAAPA) found associations with loci (some strongly associate and some only with marginal evidence) previously discovered in non-African populations; however, they also reported associations with two novel loci that may be specific to asthma risk in African ancestry populations.(17)

Environmental exposures may also play a role in these disparities. For example, black children tend to have higher blood lead levels than White children.(18) However, it is difficult to tease apart the effects of SES and environmental exposures in our region and likely other regions as well as they are highly correlated, and unfortunately, we do not have measures of toxicant exposures or associated biomarkers in the WHEALS children.

Further complicating these relationships is the "diminished returns" of SES for non-white individuals which is a hypothesis arguing that non-white and other minority groups receive smaller health effects of family SES on health outcomes compared with White children.(19–21) This means that it is unlikely that simply changing SES factors will improve the health of Black children, but that we should look to social structure, segregation and structural racism, as well as resilience and coping strategies to understand this paradox.(22) These factors may be modifying the effects of SES or other interventions given the psychological costs associated with upward movement in SES for black individuals.(23)

These psychological costs or effects of exposure to racism and racial discrimination could be acting through epigenetic mechanisms. In a study of 152 adult black women in Connecticut (IntergGEN study), experience of perceived racism and discrimination from two validated questionnaires (Major Life Discrimination – MLD and Race-Related Events – RES) was associated with DNA methylation.(24) The importance of epigenetics in research on the development and management of asthma and allergy are gaining attention (25–27); however,

progress will be limited by the lack of both non-white participants and measures of perceived racism and discrimination in key studies.

This study was not specifically designed to examine racial differences for all outcomes examined and the study was not necessarily powered to detect small differences between subgroups. Limitations of this study include lack of measurement of toxicant exposures such as lead and pesticides and non-toxicant exposures such as stress, coping and resilience, and the built environment. However, there are numerous strengths to these analyses. The robust analytical approach addressing both loss to follow-up and an extensive panel of confounders makes these results novel. The subgroup analyses assessing effect modification are another unique strength of this work. Further, the early life factors were not recalled, but were collected concurrent in pregnancy and early life.

Unfortunately, as the list of publications documenting these racial differences grows, it has become clearer that we have made little progress in eradicating these disparities. If we identify the sources of the disparities, all individuals will be helped. But, to accomplish this, a study designed specifically to address this question is needed – it is no longer sufficient to conduct secondary data analyses in studies, or pooled analyses across multiple studies that have variability in exposure and outcome assessment, not originally powered to address racial disparities. An appropriately powered study with extensive toxicant and non-toxicant exposure assessment will be needed – especially a study with novel exposures and analytical approaches to examine the main and modifying effects of structural barriers such as psychological expense associated with upward mobility and resilience in managing that expense.

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Table 1:

Comparison of black and white children included and excluded from analysis, before and after inverse probability weighting (IPW) to account for loss to follow-up.

Covariate	Level	Included in Analysis[1]		Before IPW		After IPW	
		No N=572	Yes N=481	Standardized Difference[2]	p-value[3]	Standardized Difference[2]	p-value[3]
		N (Col %) or N, Mean±SD					
Household Income	<$20K	94 (16.4)	51 (10.6)	0.28	<0.05	0.04	0.980
	20-<$40K	141 (24.7)	109 (22.7)				
	40K-<$80K	155 (27.1)	129 (26.8)				
	$80K-<$100K	47 (8.2)	67 (13.9)				
	≥$100K	56 (9.8)	70 (14.6)				
	Refused to Answer	79 (13.8)	55 (11.4)				
Maternal Education	<HS diploma	47 (8.2)	15 (3.1)	0.43	<0.05	0.01	0.999
	HS diploma	125 (21.9)	72 (15)				
	Some college	295 (51.6)	227 (47.2)				
	≥Bachelor's Degree	105 (18.4)	167 (34.7)				
Maternal Marital Status	Unmarried	265 (46.3)	182 (37.8)	0.17	<0.05	0.01	0.78
	Married	307 (53.7)	299 (62.2)				
Insurance Coverage	HAP	180 (31.5)	251 (52.2)	0.68	<0.05	0.03	0.95
	Other insurance	169 (29.5)	175 (36.4)				
	No insurance	8 (1.4)	2 (0.4)				
	Refused/Don't Know/Missing	215 (37.6)	53 (11)				
Location of Residence	Suburban	218 (38.1)	209 (43.5)	−0.11	0.08	−0.01	0.78
	Urban	354 (61.9)	272 (56.5)				
Prenatal Alcohol Use	No	553 (97)	457 (95.2)	0.09	0.13	−0.02	0.62
	Yes	17 (3)	23 (4.8)				
Prenatal Environmental Tobacco Smoke (ETS) Exposure	No	386 (67.5)	361 (75.1)	−0.17	0.01	−0.01	0.77
	Yes	186 (32.5)	120 (24.9)				
Prenatal Indoor Dog(s)	No	437 (76.4)	354 (73.6)	0.06	0.30	−0.01	0.81
	Yes	135 (23.6)	127 (26.4)				
Prenatal Indoor Cat(s)	No	478 (83.6)	399 (83)	0.02	0.79	0.03	0.56
	Yes	94 (16.4)	82 (17)				
Parental History of Doctor-Diagnosed Allergies	No	368 (73.3)	304 (74.1)	0.08	0.78	0.02	0.94
	Yes	134 (26.7)	106 (25.9)				
Mode of Delivery	Vaginal	358 (62.9)	301 (62.7)	0.01	0.94	0.01	0.91
	C-Section	211 (37.1)	179 (37.3)				
Season of Birth	Winter	116 (20.3)	103 (21.4)				

Covariate	Level	Included in Analysis[1]		Before IPW		After IPW	
		No N=572	Yes N=481	Standardized Difference[2]	p-value[3]	Standardized Difference[2]	p-value[3]
		N (Col %) or N, Mean±SD					
	Spring	130 (22.7)	105 (21.8)	0.04	0.92	0.001	1.000
	Summer	150 (26.2)	131 (27.2)				
	Fall	176 (30.8)	142 (29.5)				
Child Sex	Male	280 (49)	239 (49.7)	−0.01	0.83	0.03	0.42
	Female	291 (51)	242 (50.3)				
Child Race	White	149 (26)	118 (24.5)	0.03	0.57	−0.003	0.95
	Black	423 (74)	363 (75.5)				
Maternal Age at Birth		572, 29.0±5.2	481, 30.3±5.3	0.24	<0.05	−0.004	0.93
Gestational Age (weeks)		557, 38.7±1.9	474, 38.8±1.7	0.05	0.38	−0.0003	0.99
Birthweight z-score		532, −0.2±0.9	456, −0.1±1.0	0.15	<0.05	0.01	0.88
Number of Older Siblings		572, 1.2±1.3	481, 1.0±1.2	−0.14	<0.05	−0.02	0.66

[1] Among the 1,053 black or white children in the WHEALS cohort.

[2] Difference in means or proportions divided by standard error; imbalance defined as absolute value greater than 0.20.

[3] Calculated by ANOVA for numerical covariates and the chi-square test for categorical covariates.

Table 2.

Racial differences in binary allergic outcomes at age 10, before and after covariate adjustment and multiple imputation.

		Sensitized to ≥1 sIgE		SPT+			Eczema			Asthma			PC_{20}≤25 mg/ml		
Crude N (%)[1]	**Black**	**223 (62.8%)**		**222 (77.4%)**			**83 (24.1%)**			**86 (25.8%)**			**181 (56.6%)**		
	White	**45 (41.3%)**		**72 (74.2%)**			**12 (10.7%)**			**9 (8.1%)**			**52 (49.1%)**		
Adjustment Covariate	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**
Unadjusted	464	1.85 (1.2, 2.85)	<.05	384	0.95 (0.55, 1.65)	0.86	456	2.93 (1.47, 5.84)	<.05	444	4.80 (2.23, 10.32)	<.05	426	1.28 (0.82, 1.99)	0.23
Household Income	464	2.01 (1.26, 3.21)	<.05	384	0.91 (0.5, 1.63)	0.75	456	3.13 (1.52, 6.43)	<.05	444	3.97 (1.8, 8.76)	<.05	426	1.23 (0.77, 1.98)	0.39
Maternal Education	464	2.17 (1.36, 3.46)	<.05	384	1.01 (0.57, 1.8)	0.97	456	3.77 (1.83, 7.79)	<.05	444	4.22 (1.92, 9.28)	<.05	426	1.26 (0.79, 2.02)	0.34
Maternal Marital Status	464	1.95 (1.23, 3.08)	<.05	384	1.07 (0.59, 1.93)	0.82	456	2.79 (1.37, 5.7)	<.05	444	4.57 (2.09, 10.01)	<.05	426	1.46 (0.91, 2.35)	0.12
Make monthly mortgage or rental payments	422	1.7 (1.08, 2.7)	<.05	349	0.83 (0.45, 1.52)	0.55	415	2.52 (1.25, 5.11)	<.05	405	4.41 (2.03, 9.6)	<.05	385	1.43 (0.89, 2.29)	0.14
Parental history of doctor-diagnosed allergies	397	1.71 (1.06, 2.76)	<.05	329	0.8 (0.44, 1.43)	0.45	389	4.01 (1.73, 9.29)	<.05	377	5.48 (2.37, 12.68)	<.05	361	1.08 (0.67, 1.75)	0.75
Prenatal indoor pet(s)	464	1.65 (1.02, 2.66)	<.05	384	0.98 (0.54, 1.79)	0.96	456	2.42 (1.16, 5.06)	<.05	444	3.85 (1.73, 8.56)	<.05	426	1.32 (0.81, 2.14)	0.27
Prenatal ETS exposure	464	1.86 (1.2, 2.88)	<.05	384	0.94 (0.54, 1.63)	0.83	456	2.96 (1.48, 5.93)	<.05	444	4.83 (2.24, 10.41)	<.05	426	1.27 (0.81, 1.99)	0.30
Prenatal antifungal use	377	2.39 (1.46, 3.89)	<.05	310	1.26 (0.69, 2.28)	0.45	370	2.93 (1.37, 6.23)	<.05	360	5.44 (2.29, 12.95)	<.05	346	1.36 (0.82, 2.26)	0.23
Prenatal antifungal use	377	2.32 (1.43, 3.76)	<.05	310	1.27 (0.71, 2.29)	0.42	370	2.62 (1.24, 5.5)	<.05	360	5.38 (2.28, 12.71)	<.05	346	1.38 (0.84, 2.26)	0.20
Ever breastfed their child	445	1.85 (1.19, 2.87)	<.05	369	0.94 (0.55, 1.62)	0.84	437	2.54 (1.29, 5.03)	<.05	426	3.88 (1.82, 8.24)	<.05	412	1.3 (0.83, 2.02)	0.25
Season of birth	464	1.94 (1.25, 3.02)	<.05	384	0.96 (0.55, 1.66)	0.88	456	2.91 (1.46, 5.81)	<.05	444	4.95 (2.29, 10.67)	<.05	426	1.26 (0.81, 1.97)	0.31
Mode of delivery	463	1.83 (1.18, 2.84)	<.05	383	0.94 (0.54, 1.63)	0.82	455	2.85 (1.43, 5.7)	<.05	443	4.72 (2.19, 10.17)	<.05	425	1.25 (0.8, 1.94)	0.33
Child sex	464	1.89 (1.22, 2.93)	<.05	384	0.95 (0.55, 1.64)	0.86	456	2.93 (1.47, 5.86)	<.05	444	4.97 (2.3, 10.71)	<.05	426	1.29 (0.83, 2.01)	0.26

		Sensitized to ≥1 sIgE		SPT+			Eczema			Asthma			PC_{20}≤25 mg/ml		
Crude N (%)[1]	**Black**	**223 (62.8%)**		**222 (77.4%)**			**83 (24.1%)**			**86 (25.8%)**			**181 (56.6%)**		
	White	**45 (41.3%)**		**72 (74.2%)**			**12 (10.7%)**			**9 (8.1%)**			**52 (49.1%)**		
Adjustment Covariate	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**	**N**	**OR (95% CI)[2]**	**p-value**
Maternal age at birth	464	1.96 (1.25, 3.08)	<.05	384	0.98 (0.56, 1.72)	0.94	456	3.39 (1.67, 6.87)	<.05	444	5.07 (2.33, 11)	<.05	426	1.3 (0.82, 2.04)	0.26
Maternal BMI-first measured in pregnancy	437	1.87 (1.19, 2.92)	<.05	360	0.91 (0.52, 1.59)	0.74	430	3.67 (1.7, 7.92)	<.05	418	5.29 (2.36, 11.84)	<.05	400	1.36 (0.86, 2.15)	0.18
Birthweight z-score	441	1.97 (1.22, 3.17)	<.05	362	1.22 (0.67, 2.2)	0.52	433	3.4 (1.61, 7.17)	<.05	421	3.85 (1.74, 8.5)	<.05	404	1.47 (0.89, 2.43)	0.13
Gestational age at delivery	458	2.13 (1.36, 3.35)	<.05	377	1.07 (0.61, 1.86)	0.82	449	2.7 (1.35, 5.41)	<.05	437	4.08 (1.89, 8.79)	<.05	421	1.15 (0.73, 1.8)	0.55
Number of older siblings	464	1.93 (1.24, 2.99)	<.05	384	0.94 (0.54, 1.63)	0.82	456	2.98 (1.49, 5.96)	<.05	444	4.74 (2.2, 10.21)	<.05	426	1.33 (0.85, 2.08)	0.21
Fully Adjusted-Without Imputation	263	2.47 (1.08, 5.63)	<.05	215	1.49 (0.53, 4.21)	0.45	258	7.84 (2.2, 27.98)	<.05	250	3.79 (1.15, 12.53)	<.05	237	2.98 (1.21, 7.34)	0.02
Fully Adjusted-With Imputation	481	2.09 (1.13, 3.84)	<.05	481	1.04 (0.5, 2.13)	0.92	481	2.71 (1.13, 6.55)	<.05	481	3.00 (1.21, 7.47)	<.05	481	2.12 (1.15, 3.92)	0.02

[1] Prior to IPW.

[2] Odds of specified outcome in black versus white children, respectively. All models use IPWs to account for loss to follow-up.

Table 3:

Examining potential effect modification in the association between race and binary allergic outcomes at age 10.

Effect Modifier	Sensitized to ≥1 sIgE	SPT+	Eczema	Asthma	PC_{20}≤25 mg/ml
	Interaction p-value[1]				
Mode of delivery	0.21	0.41	0.95	0.11	0.93
First born child	0.67	**0.095**[3]	0.75	0.71	0.25
Child sex	0.71	0.94	0.57	0.93	**0.091**[4]
Prenatal indoor dog(s)	**<0.05**[2]	0.18	0.76	0.23	0.93
Ever breastfed their child	0.99	0.20	0.55	0.80	0.31

[1] Interaction term added to the fully-adjusted imputation model, with IPWs to account for loss to follow-up (N=481).

[2] Significant racial difference in dog-exposed children only: OR (95% CI)=0.68 (0.29, 1.61), p=0.39; 11.18 (3.34, 37.41), p<0.05; in those unexposed and exposed to dogs, respectively.

[3] Non-significant racial differences in both subgroups: OR (95% CI)=1.72 (0.50, 5.84), p=0.39; 0.71 (0.26, 1.94), p=0.50; in those who are and are not first born children, respectively.

[4] Significant racial difference in males only: OR (95% CI)=3.46 (1.50, 7.99), p=0.004; 1.14 (0.43, 3.05), p=0.79; in males and females, respectively.

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Table 4:

Racial differences in continuous allergic outcomes at age 10, before and after covariate adjustment and multiple imputation.

		Total IgE			FEV1 (% Predicted)				FVC (% Predicted)				FEV1/FVC Ratio				FEF 25–75 (% Predicted)			
Crude Mean±SD[1]	**Black**	**79.2±4.5**			**99.4±14.7**				**105.3±13.5**				**82.8±7.9**				**87.4±28.5**			
	White	**40.6±4.4**			**100.4±10.4**				**104.0±11.1**				**84.9±6.2**				**89.2±22.6**			
Adjustment Covariate	**N**	**β[2,3]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**
Unadjusted	464	0.62	0.16	<.05	454	−0.3	1.53	0.85	451	1.7	1.44	0.24	454	−1.49	0.82	0.07	453	0.08	2.97	0.98
Household Income	464	0.59	0.17	<.05	454	0.08	1.64	0.96	451	2.01	1.54	0.19	454	−1.44	0.87	0.10	453	−0.26	3.17	0.93
Maternal Education	464	0.62	0.17	<.05	454	0.17	1.6	0.92	451	2.42	1.52	0.11	454	−1.65	0.86	0.06	453	0	3.09	0.99
Maternal Marital Status	464	0.67	0.17	<.05	454	−0.15	1.62	0.93	451	2.1	1.52	0.17	454	−1.62	0.87	0.06	453	−0.46	3.14	0.89
Make monthly mortgage or rental payments	422	0.49	0.17	<.05	411	−0.24	1.63	0.89	408	0.76	1.54	0.62	411	−0.72	0.85	0.4	410	2.46	3.14	0.43
Parental history of doctor-diagnosed allergies	397	0.55	0.18	<.05	385	0.82	1.69	0.63	382	2.93	1.56	0.06	385	−1.51	0.9	0.10	384	1.91	3.3	0.56
Prenatal indoor pet(s)	464	0.47	0.18	<.05	454	2.37	1.66	0.16	451	3.95	1.57	0.01	454	−0.8	0.9	0.37	453	4.14	3.24	0.20
Prenatal ETS exposure	464	0.62	0.16	<.05	454	−0.62	1.54	0.69	451	1.43	1.45	0.33	454	−1.49	0.83	0.07	453	−0.38	2.99	0.90
Prenatal antibiotic use	377	0.6	0.18	<.05	368	−1.27	1.73	0.47	367	0.79	1.63	0.63	368	−1.68	0.95	0.08	368	−1.21	3.46	0.73
Prenatal antifungal use	377	0.57	0.18	<.05	368	−1.4	1.7	0.41	367	0.64	1.59	0.69	368	−1.64	0.93	0.08	368	−1.41	3.4	0.68
Ever breastfed their child	445	0.54	0.16	<.05	438	0.12	1.55	0.94	435	1.58	1.43	0.27	438	−1.06	0.82	0.20	437	1.79	3.05	0.56

		Total IgE			FEV1 (% Predicted)				FVC (% Predicted)				FEV1/FVC Ratio				FEF 25–75 (% Predicted)			
Crude Mean±SD[1]	**Black**	**79.2±4.5**			**99.4±14.7**				**105.3±13.5**				**82.8±7.9**				**87.4±28.5**			
	White	**40.6±4.4**			**100.4±10.4**				**104.0±11.1**				**84.9±6.2**				**89.2±22.6**			
Adjustment Covariate	**N**	**β[2,3]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**	**N**	**β[2]**	**SE**	**p-value**
Season of birth	464	0.63	0.16	<.05	454	−0.29	1.53	0.85	451	1.67	1.44	0.25	454	−1.49	0.82	0.07	453	0.2	2.98	0.95
Mode of delivery	463	0.6	0.16	<.05	453	−0.32	1.54	0.83	450	1.59	1.45	0.27	453	−1.42	0.82	0.08	452	0.19	2.98	0.95
Child sex	464	0.64	0.16	<.05	454	−0.43	1.53	0.78	451	1.6	1.44	0.27	454	−1.58	0.81	0.05	453	0.04	2.97	0.99
Maternal age at birth	464	0.65	0.17	<.05	454	0.55	1.58	0.73	451	2.59	1.48	0.08	454	−1.42	0.85	0.09	453	0.92	3.06	0.76
Maternal BMI-first measured in pregnancy	437	0.52	0.17	<.05	428	−1.34	1.53	0.38	425	0.6	1.43	0.68	428	−1.39	0.86	0.11	427	−0.72	3.07	0.82
Birthweight z-score	441	0.63	0.18	<.05	430	0.1	1.72	0.95	427	1.62	2.66	0.10	430	−2.43	0.9	<.05	429	−0.79	3.29	0.81
Gestational age at delivery	458	0.61	0.17	<.05	448	−0.85	1.58	0.59	445	1.17	1.49	0.43	448	−1.64	0.84	0.05	447	−0.84	3.04	0.78
Number of older siblings	464	0.64	0.16	<.05	454	−0.51	1.53	0.74	451	1.55	1.45	0.29	454	−1.55	0.82	0.06	453	−0.43	2.96	0.88
Fully Adjusted-Without Imputation	263	0.19	0.29	0.52	253	1.6	2.72	0.56	252	4.28	2.41	0.08	253	−2.35	1.46	0.11	253	0.73	5.64	0.90
Fully Adjusted-With Imputation	481	0.25	0.21	0.22	481	1.78	2.04	0.38	481	4.08	1.87	<.05	481	−1.7	1.07	0.11	481	0.38	3.93	0.92

[1] Prior to IPW. Arithmetic mean and SD provided for all variables except total IgE, where geometric mean and SD is provided.

[2] Mean difference in specified outcome comparing black versus white children, respectively. All models use IPWs to account for loss to follow-up.

[3] Outcome is log-transformed, so coefficient corresponds to the mean difference in log(total IgE). Equivalently, exp(β) corresponds to the ratio of the geometric mean total IgE in black versus white children. For example, when β=0.62, exp(β)=1.86, meaning that black children have an 86% higher geometric mean of total IgE, compared to white children.

Table 5.

Examining potential effect modification in the association between race and continuous allergic outcomes at age 10.

Effect Modifier	Total IgE	FEV1 (% Predicted)	FVC (% Predicted)	FEV1/FVC Ratio	FEF 25–75 (% Predicted)
	Interaction p-value[1]				
Mode of delivery	**0.003**[2]	0.51	0.72	**0.054**[4]	**0.067**[5]
First born child	0.56	0.20	0.52	0.37	0.19
Child sex	0.61	0.32	0.38	0.74	0.18
Prenatal indoor dog(s)	**0.090**[3]	0.69	0.36	0.64	0.81
Ever breastfed their child	0.93	0.72	0.70	0.43	0.59

[1] Interaction term added to the fully-adjusted imputation model, with IPW (N=481).

[2] Significant racial difference in c-section born children only: β (SE)=0.69 (0.35), p=0.049; β (SE)=−0.02 (0.27), p=0.94; in those born via c-section and vaginally, respectively.

[3] Non-significant racial differences in both subgroups: β (SE)=0.73 (0.38), p=0.054; β (SE)=−0.20 (0.28), p=0.49; in children exposed and unexposed to dogs, respectively.

[4] Significant racial difference in c-section born children only: β (SE)= −4.25 (1.89), p=0.024; β (SE)= −0.33 (1.36), p=0.81; in those born via c-section and vaginally, respectively.

[5] Non-significant racial differences in both subgroups: β (SE)= −9.51 (6.62), p=0.15; β (SE)= 7.43 (5.24), p=0.16; in those born via c-section and vaginally, respectively.

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