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COVID-19 vaccines for children: Racial and ethnic disparities in New York City

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A R T I C L E I N F O

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A B S T R A C T

Vaccination is an indispensable tool to reduce negative outcomes due to COVID-19. Although COVID-19 disproportionately affected lower income and Black and Hispanic communities, these groups have had lower population-level uptake of vaccines. Using detailed cross-sectional data, we examined racial and ethnic group differences in New York City schoolchildren becoming fully vaccinated (two doses) within 6 months of vaccine eligibility. We matched school enrollment data to vaccination data in the Citywide Immunization Registry, a census of all vaccinations delivered in New York City. We used ordinary least squares regression models to predict fully vaccinated status, with key predictors of race and ethnicity using a variety of different control variables, including residential neighborhood or school fixed effects. We also stratified by borough and by age. The sample included all New York City public school students enrolled during the 2021–2022 school year. Asian students were most likely to be vaccinated and Black and White students least likely. Controlling for student characteristics, particularly residential neighborhood or school attended, diminished some of the race and ethnicity differences. Key differences were also present by borough, both overall and by racial and ethnic groups. In sum, racial and ethnic disparities in children's COVID-19 vaccination were present. Vaccination rates varied by the geographic unit of borough; controlling for neighborhood characteristics diminished some disparities by race and ethnicity. Neighborhood demographics and resources, and the attributes, culture and preferences of those who live there may affect vaccination decisions and could be targets of future efforts to increase vaccination rates.

1. Introduction

Vaccination is one of the most valuable tools to reduce the severity of COVID-19 for adults as well as children. (Kuehn, 2021; Klein et al., 2022) While the severity of cases and number of hospitalizations among children were low relative to other age groups, some children have severe complications and risk is elevated among children with underlying health conditions and chronic illness. (Leeb et al., 2020; Shekerdemian et al., 2020; Moreira et al., 2021) Further, vaccinating children can help reduce population-level rates of illness and death. (McLaughlin et al., 2022; Cohen-Stavi et al., 2022) Vaccines have been proven safe and effective and are recommended by all major health-related groups, including the Centers for Disease Control and Prevention (CDC) and the American Academy of Pediatrics. (Col, 2022; Walensky, 2022) Nevertheless, uptake of vaccines for children has been quite low. As of March 1, 2023, more than 8 months since vaccines were approved on an emergency use basis for children older than 6 months of age, and nearly 2 years since emergency use basis approval for adolescents, only 43% of US children age 6 months to 17 years had received at least one dose. (Cull, 2022) Vaccination was especially low among younger groups; 12% of children 6 months – 4 years old had received at least one dose, compared with 39% of children ages 5–11 and 68% of children ages

Abbreviations: CDC, Centers for Disease Control and Prevention; NYC, New York City; SPHR, Student Population Health Registry; ELL, English language learner.

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12–17. This variation by age group is not due solely to the earlier availability of vaccines for older children, as national uptake in the first 15 weeks of eligibility was 8% among children under age 5, 31% among children ages 5–11, and 40% among those 12–17 years old, and rates have leveled off across all age groups. (Cull, 2022).

While age patterns are clear, less is known about disparities in vaccinations for children across racial and ethnic groups. COVID-19 disproportionately affected lower income Black and Hispanic communities, consistent with other health disparities and social inequities. As with adults, there were racial and ethnic disparities in children's rate of illness, with Black or Hispanic children much more likely to be hospitalized than white children. (Artiga et al., 2021; Vicetti Miguel et al., 2022) Although the availability of national data is limited, (Ngô, 2022) hospitalizations were elevated among Black children compared to White children during the delta variant (2021) and accounted for 47% of child hospitalizations during the beginning of the omicron variant (2022). (Vicetti Miguel et al., 2022) Targeted, culturally-appropriate strategies to remove structural barriers to vaccine access or address mistrust can be developed and implemented if disparities in vaccine uptake are identified. Within the small subset of states that report data to the CDC, (Ndugga et al., 2022) race and ethnicity is correlated with vaccine uptake among adults and children combined, though the CDC cautions that due to missing data, the percentages are not generalizable. The highest all-ages uptake was among Asian Americans (66.3% fully vaccinated as of March 29, 2023), American Indian/Alaska Natives (65.1%) and Native Hawaiian/Pacific Islanders (64.3%), and the lowest uptake was among non-Hispanic Black and non-Hispanic White groups (44.9% and 51.9%, respectively). (Centers for Disease Control and Prevention. n.d.) Data on children are not presented separately from adults. More representative but perhaps still lacking, several national surveys of parents addressed COVID-19 vaccination for children. The CDC recently published an analysis of the National Immunization Survey—Child COVID (Singh et al., 2022) Module on self-reported vaccination status. This national random digit dial phone survey of parents found that vaccination was highest among Asian children (75.2% with at least 1 dose), followed by Hispanic (49.1%), White (45.0%) and Black (43.1%). (Valier et al., 2023) Analyses of the US Census Bureau's Household Pulse Surveys (response rate 5–6%) (U.S. Census Bureau, 2021.) found non-Hispanic Black and socio-economically disadvantaged adults reported children in their households were significantly least likely to be vaccinated, while Asian and Hispanic adults were significantly more likely to report that children in their households were vaccinated. (Singh et al., 2022; Nguyen et al., 2022) Surveys of parents found intent to vaccinate their children varied by racial and ethnic group (Valier et al., 2023; Stephenson, 2022; Hart et al., 2023; Romer et al., 2022) with Black parents the least likely to signal intent to vaccinate, including one survey conducted in New York City (NYC), where the current study is situated. (Teasdale et al., 2021) The CDC reported that during the first two months of vaccine authorization for children ages 5–11 (Nov. 2 – Dec. 31, 2021), 24% received at least one dose, with an overrepresentation of Asian children compared to their proportion in the population, and underrepresentation among Non-Hispanic Black, Non-Hispanic White and Hispanic children. (Murthy et al., 2022) Disparities in vaccination rates have been observed between schools with the majority of students belonging to a single racial or ethnic group. (Elbel et al., 2022).

To fill the gap in information about racial and ethnic disparities in children's COVID-19 vaccination, we used student records from all NYC public school students to examine racial and ethnic disparities in being fully vaccinated (two doses) within 6 months of vaccine rollout. Subsequently, we determined the extent to which neighborhood and school context shaped the relationship between race and ethnicity and vaccination. This work is important given the critical role of neighborhoods and schools in fostering disparities historically and serving as a potential mediator of disparities present today.

2. Methods

We used the recently developed Student Population Health Registry (SPHR), an inclusive, longitudinal database of administrative records for all NYC public school students created jointly by the NYC Department of Health and Mental Hygiene and NYC Department of Education. SPHR links together multiple health- and education-oriented municipal data sources at the child-level. We matched the public school students' data to vaccination data in the Citywide Immunization Registry, the city's comprehensive record of immunizations received by every city resident. Providers are mandated to submit COVID-19 vaccinations to the Registry within 24 h of administration. With this, we examined disparities in vaccination by race and ethnicity overall and by age and borough of residence. We focused on only public school students because SPHR includes the greatest breadth of information on these students.

2.1. *Data and variables*

Data on all 1,077,311 children enrolled in NYC public schools during the 2021–2022 school year were included in the sample drawn from SPHR and matched to their vaccination record in the Citywide Immunization Registry. Our outcome of interest was fully vaccinated status (for almost all children in this period, two doses of the Pfizer vaccine) within 180 days of vaccine eligibility for their age group in New York State (16–18, 12–15, or 5–11). In New York state, most individuals ages 16–18 became eligible for the COVID-19 vaccine on the same date (April 6, 2021) because the state staggered eligibility by risk of severe disease to meet demand (those with specific health conditions were eligible earlier). Those aged 12–15 became eligible on May 13, 2021 and those 5–11 on November 4, 2021. Limiting the time period to 180 days provided a consistent comparison across time because the vaccine was authorized at different times for the three age groups. The sample consisted of all students in the NYC public school system ages 5–18, excluding those missing data on sex, race and ethnicity, age, ever enrolled in Medicaid, English language learner status, school attended, or residential address. To assure a consistent sample, we excluded students who "aged into" eligibility, restricting the sample to students who were immediately eligible at the time vaccines became available to their age group (for example, we excluded students who turned 16 after the date vaccinations were available for ages 16 + and before it became available for those ages 12–15). Thus, excluded from our analytic sample were (the following list is not mutually exclusive): a) students who were not observed or uniquely identified in the Citywide Immunization Registry (n = 21,957), b) recorded receiving more than 3 vaccine doses, given some booster availability for older age groups (n = 916), c) received their first dose before vaccines were publicly available (n = 2,686), d) never eligible for the vaccine during the study period (n = 77,564; i.e., below age 5 as of May 27, 2022), e) age 19 and above (n = 18,967), f) invalid grade (n = 7,598), g) missing race (n = 205), h) attending a school for students with disabilities (n = 1,096) or an alternative school (n = 5,667), i) residential address invalid or missing (n = 4,180), j) missing English language learner status (n = 8,967), and k) students who aged into vaccine eligibility (n = 42,660; who were not eligible by age on the date the vaccine was first authorized for their age group).

Race and ethnicity data were parent/guardian-reported and coded in the following mutually exclusive and exhaustive categories: Hispanic, non-Hispanic Black (Black, throughout), non-Hispanic White (White, throughout), Asian, and Other (American Indian or Alaskan Native, Native Hawaiian or other Pacific Islander, and Multi-racial students). We also included in our model indicators for whether the student had ever been enrolled in Medicaid, whether they ever were an English language learner (currently or previously identified as such by NYC Department of Education), and sex, and dummy variables for age in years, residential borough and/or census tract of residence (depending on the model, as defined below), and school attended in the 2021–22 school year.

2.2. Statistical analysis

We first compiled descriptive statistics for the sample, including percentage vaccinated by subgroup. We looked at similar data by borough. For additional descriptive statistics, we plotted the daily percent vaccinated for the first 180 days following eligibility, by three relevant age groups (defined by vaccine eligibility timing: 16–18, 12–15, 5–11). We created similar plots for each racial subgroup, centered on each age group's eligibility date, showing the vaccination trajectories and endpoints for each age group for each race and ethnicity.

We used ordinary least squares (OLS) multivariable models to predict fully vaccinated status (two doses of Pfizer within 180 days), with our key predictors of race and ethnicity, adding successively more covariates – age, other student characteristics, then either residential neighborhood or school fixed effects. We set up the models in this way to first look at the correlations with race and ethnicity before "explaining away" such differences with other control variable. OLS is appropriate with a binary outcome such as ours, particularly when a) the outcome is usually not predicted at the extremes (i.e., close to 0 or 1) (Hellevik, 2009) and b) the model estimates associations between the independent and outcome variables. (Mood, 2010) Under those conditions, OLS performs equal or better to logit/probit, and in addition it allows simpler interpretation, particularly of the coefficients. (Elbel et al., 2020) We stratified the model by residential borough (in NYC, these are county units) to gauge heterogeneity in results across areas with different sociodemographic characteristics, and then by age to determine how different age groups, with different vaccine approval timelines, varied. In each model, we estimated predicted probabilities with the margins command in Stata version 17 (StataCorp). Predicted probabilities represent the likelihood (in percent) of the group member being fully vaccinated within 180 days, controlling for the other characteristics included in the model. We present statistical significance relative to the reference group noted for each set of indicator variables. This research protocol was determined to meet the guidelines for safety and privacy in human subjects research by the New York University Langone Health Institutional Review Board. A statement of exemption from Federal regulations was issued.

3. Results

Our sample size after exclusions was 867,488. The sample was 48.8% female (Table 1). The largest racial or ethnic group was Hispanic (41.4%), followed by Non-Hispanic Black (24.4%), Asian or Asian American (16.4%) and Non-Hispanic White (14.3%). The 5–11 age group was 55.6% of the sample, 74.8% had ever been enrolled in Medicaid and 27.1% had ever been categorized as an English language learner by the NYC Department of Education. Table 1 also presents unadjusted percent vaccinated, ranging from 27.4% for Black students to 78.5% for Asian students.

We present the data by borough in Table 1. We found borough level differences in student-level vaccination percentages, with Manhattan (59.5%) and Queens (58.4%) having the highest percent vaccinated and Staten Island (40.4%) the lowest. We also observe differences in the race and ethnicity of students who reside in different boroughs. Hispanic students were the largest racial or ethnic group in the Bronx (62.1%), Manhattan (43.7%) and Queens (39/9%), while Black students were the largest in Brooklyn (33.3%) and White students in Staten Island (39.6%). With the exception of "other", every borough had at least 10% from each racial and ethnic group under study.

Panel A of Fig. 1 presents vaccination percentage by age group for

Table 1
Sociodemographic characteristics and percentage fully vaccinated (unadjusted), of children aged 5–18 in the New York City Student Population Health Registry, overall and by borough of residence, at the end of the first 180 days of vaccine eligibility.

	Overall (N = 867,488)		Bronx (N = 201,109)		Brooklyn (N = 264,231)		Manhattan (N = 94,572)		Queens (N = 250,614)		Staten Island (N = 56,962)	
	Percent sample	Vax. (%)	Percent sample	Vax. (%)	Percent sample	Vax. (%)	Percent sample	Vax. (%)	Percent sample	Vax. (%)	Percent sample	Vax. (%)
Overall		51.0		44.0		48.4		59.5		58.4		40.4
Sex												
Female	48.8	51.7	49.1	44.9	48.8	49.1	49.2	60.4	48.4	59.0	48.5	40.9
Male	51.2	50.3	50.9	43.2	51.2	47.8	50.8	58.6	51.6	57.8	51.5	39.9
Race or ethnicity												
Asian	16.4	78.5	4.1	69.0	17.0	77.0	10.8	86.6	28.2	79.7	14.5	76.1
Black	24.4	37.4	27.9	39.0	33.3	35.5	20.5	38.9	16.2	39.4	12.7	33.1
Hispanic	41.4	49.0	62.1	45.1	28.8	47.3	43.7	51.8	39.9	55.3	30.0	40.3
Other[1]	3.4	54.7	2.2	43.4	3.2	52.1	4.9	68.1	4.3	58.8	3.1	35.1
White	14.3	47.3	3.7	35.3	17.7	46.4	20.1	80.3	11.5	43.4	39.6	30.1
Age group (in years)												
5–11	55.6	44.4	55.2	36.8	55.8	42.9	56.8	56.6	55.4	50.5	55.7	30.5
12–15	33.2	60.0	33.3	54.1	33.1	56.2	32.5	64.2	33.4	68.7	33.1	53.0
16–18	11.2	56.9	11.4	49.6	11.1	53.0	10.8	60.2	11.2	66.8	11.3	52.2
Ever enrolled in Medicaid[2]												
Yes	74.8	48.2	85.7	43.0	75.4	44.7	64.1	49.0	72.2	58.2	63.2	41.1
No	25.2	59.1	14.3	49.9	24.6	59.7	35.9	78.1	27.8	59.0	36.8	39.1
Ever English language learner[3]												
Yes	27.1	55.8	27.6	49.0	26.7	51.9	19.6	59.0	32.1	63.5	17.7	53.4
No	72.9	49.2	72.4	42.1	73.3	47.2	80.4	59.6	67.9	56.0	82.3	37.6

Notes: Calculations based a the analytical sample of 867,488 enrolled in New York City public schools in the 2021–2022 school year. Percent sample may not sum to 100 due to rounding. Vax. (%) indicates the percentage that was fully vaccinated as of May 27, 2022.

[1] "Other" includes American Indian or Alaskan Native, Native Hawaiian or Other Pacific Islander, and Multi-racial students.

[2] "Ever enrolled in Medicaid" indicates if the student was ever assigned a Medicaid ID.

[3] Ever English language learner indicates if the student was ever classified as an English language learner by the New York City Department of Education.

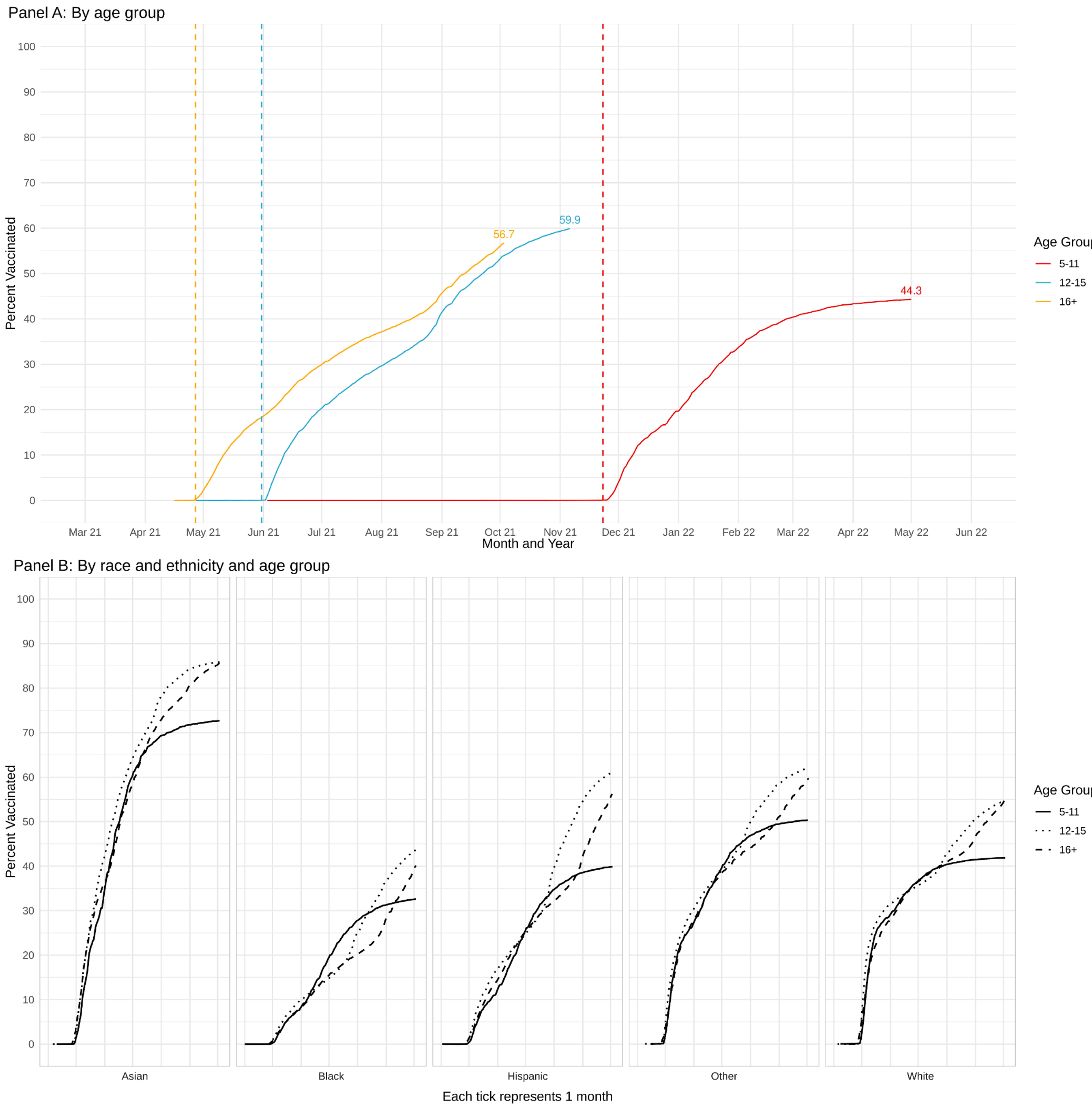

Fig. 1. Daily proportion of NYC public school students fully vaccinated within 180 days of eligibility. Calculations are based on an analytical sample constructed with data on children enrolled in NYC public schools during the 2021–2022 school year that satisfy the data restrictions of the paper. Each line corresponds to the percentage of children by age group for the first 180 days following each age group's first eligibility. Panel B: lines are centered on and start from the date each age group became eligible for the vaccine.

the first 180 days following each age group's first eligibility. The rate of increase in vaccination varied by age group and decelerated at different points, with 5–11 year olds at the lowest percent vaccinated after the initial 180 day period.

Controlling for sex and age, females had a vaccination percentage of 51.8% and males 50.2% (Table 2). Asian students had the highest vaccination rate (78.7%), while Black students had the lowest (37.0%). Adding other student level controls, neither Medicaid enrollment nor English language learner (ELL) status, appreciably changed these rates. Students ever-enrolled in Medicaid had lower vaccination rates (47.6%) than others (60.8%); the gap between ELL (50.3%) versus non-ELL (51.2%) was more modest. Some racial and ethnic differences were reduced by adding neighborhood or school fixed effects. Notably, the disparity between Black students and White students was reduced to a 1–2 percentage point gap, and the difference between Asian students and all other racial and ethnic groups decreased as well.

When examined by borough of home residence, substantial differences across racial and ethnic groups emerged (Table 3). For example, White students in Manhattan were vaccinated at higher rates (67.7%) than Black students (46.1%), Hispanic students (56.5%) and Other students (62.1%), although not higher than Asian students (80.2%); while White students had the lowest vaccination rate of any racial or

Table 2
Predicted probabilities (in %) to be fully vaccinated at the end of the first 180 days of vaccine eligibility, for children aged 5–18 in the New York City Student Population Health Registry.

	Model (1)	Model (2)	Model (3)	Model (4)
	% (SE)	% (SE)	% (SE)	% (SE)
Overall	51.0	51.0	51.0	51.0
Sex				
Male *(ref.)*	50.2 (0.1)	50.2 (0.1)	50.2 (0.1)	50.5 (0.1)
Female	51.8 (0.1)***	51.7 (0.1)***	51.7 (0.1)***	51.5 (0.1)***
Race and ethnicity				
Asian	78.7 (0.1)***	79.0 (0.1)***	75.2 (0.1)***	74.2 (0.1)***
Black	37.0 (0.1)***	37.4 (0.1)***	41.3 (0.1)***	41.1 (0.1)***
Hispanic *(ref.)*	48.8 (0.1)	49.9 (0.1)	49.7 (0.1)	50.3 (0.1)
Other	56.2 (0.3)***	54.2 (0.3)***	51.9 (0.3)***	54.8 (0.3)***
White	47.9 (0.1)***	44.2 (0.1)***	43.1 (0.1)***	42.2 (0.1)***
Ever enrolled in Medicaid				
Yes *(ref.)*	–	47.6 (0.1)***	48.8 (0.1)***	48.8 (0.1)***
No	–	60.8 (0.1)***	57.4 (0.1)***	57.3 (0.1)***
Ever English language learner				
Yes *(ref.)*	–	50.3 (0.1)***	49.9 (0.1)***	50.9 (0.1)***
No	–	51.2 (0.1)***	51.3 (0.1)***	51.0 (0.1)***
Model Covariates				
Age Dummies	Yes	Yes	Yes	Yes
Neighborhood FE	No	No	Yes	No
School FE	No	No	No	Yes
R-squared	0.098	0.110	0.152	0.168

Notes: The table presents the coefficients from a linear probability model of the probability of being fully vaccinated 180 days after the age of eligibility. Each specification controls for the variables included in their column. The basic model (1) includes sex, race and ethnicity, and age dummies only. Hispanic was the referent group for race and ethnicity because it includes the largest number of students. Subsequent models include some combination of student-level controls (ever Medicaid, ever English language learner), neighborhood and/or school fixed effects. Robust standard errors are calculated. N for each model is 867,488. Significance level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

ethnic group in Staten Island (29.8%, compared with 33.9–75.7%), the Bronx (32.9% compared with 39.8%-66.3%), and Queens (42.5% compared with 46.5%-76.9%). The Medicaid gap varied by borough. The largest gap was for Manhattan (53.8% vaccinated with Medicaid versus 69.6% without Medicaid) and the smallest in Queens (57.3% vaccinated with Medicaid versus 61.3% without Medicaid).

Separating the results by age group, we saw some relatively subtle differences in the relationships between race and ethnicity and vaccination by age (Table 4). For example, while older Hispanic students (ages 12–15, 16 +) were more likely to have been vaccinated than older Black or White students (57.4–61.7% compared with 44.3–50.8%), among younger children (ages 5–11) the difference between racial and ethnic groups' vaccination rates is reduced (41.1% compared with 36.8%).

Panel B of Fig. 1 also presents results broken down by age and race and ethnicity. The average effect masks meaningful variation in the speed (timing) by race group. For example, Black 5–11 year olds had an initially higher vaccination rate than older Black children, relative to other racial and ethnic groups. Across all racial subgroups, vaccination rates among students aged 12–15 and 16 + were on a continued upward trajectory at the end of the sixth months of eligibility relative to ages 5–11, which flattened out more rapidly.

Table 3
Predicted probabilities (in %) to be fully vaccinated at the end of the first 180 days of vaccine eligibility, stratified by home borough, for children aged 5–18 in the New York City Student Population Health Registry.

	Bronx	Brooklyn	Manhattan	Queens	Staten Island
	% (SE)	% (SE)	% (SE)	% (SE)	% (SE)
Overall	44.0	48.4	59.5	58.4	40.4
Sex					
Male *(ref.)*	43.2 (0.2)	47.7 (0.1)	58.7 (0.2)	57.7 (0.1)	40.0 (0.3)
Female	44.9 (0.2)***	49.2 (0.1)***	60.3 (0.2)***	59.1 (0.1)***	40.8 (0.3)*
Race and ethnicity					
Asian	66.3 (0.5)***	77.1 (0.3)***	80.2 (0.4)***	76.9 (0.2)***	75.7 (0.5)***
Black	39.8 (0.2)***	37.5 (0.2)***	46.1 (0.4)***	46.5 (0.3)***	33.9 (0.6)***
Hispanic *(ref.)*	45.1 (0.1)	48.1 (0.2)	56.5 (0.3)	54.5 (0.2)	40.4 (0.4)
Other	43.5 (0.7)*	47.3 (0.5)	62.1 (0.7)***	61.0 (0.5)***	36.8 (1.1)**
White	32.9 (0.6)***	42.1 (0.2)***	67.7 (0.4)***	42.5 (0.3)***	29.8 (0.3)***
Ever enrolled in Medicaid					
Yes *(ref.)*	43.0 (0.1)	45.5 (0.1)	53.8 (0.2)	57.3 (0.1)	38.1 (0.2)
No	50.4 (0.3)***	57.3 (0.2)***	69.6 (0.3)***	61.3 (0.2)***	44.3 (0.3)***
Ever English language learner					
Yes *(ref.)*	46.1 (0.2)	43.8 (0.2)	60.3 (0.4)	57.0 (0.2)	42.7 (0.5)
No	43.2 (0.1)***	50.1 (0.1)***	59.3 (0.2)***	59.1 (0.1)***	39.9 (0.2)***
Model covariates					
Age Dummies	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes
R-squared	0.063	0.178	0.169	0.155	0.172
Observations	201,109	264,231	94,572	250,614	56,962

Notes: The table shows the predicted probability for each subgroup based on the estimated coefficients of the linear probability model of the probability of being fully vaccinated 180 days after the age of eligibility. The sample is first stratified by students' home borough. Results are then estimated using the full model with ordinary least squares on each stratified subsample. The full model includes sex, race and ethnicity, age dummies, student-level controls, and neighborhood fixed effects. Hispanic was the referent group for race and ethnicity because it includes the largest number of students. For overall estimates with all five boroughs, see Model (4) of Table 2. Significance levels are calculated on the difference of the predicted probability for a particular subpopulation with respect to their group of reference. Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Conclusions

Our overall findings mirror those of the CDC's nationally representative survey of parents reporting children's vaccination status, (Valier et al., 2023) and provide evidence to support parents' vaccine hesitancy correlated with their racial and ethic identity found in many other surveys. (Singh et al., 2022; Nguyen et al., 2022; Stephenson, 2022; Hart et al., 2023; Romer et al., 2022) With vaccination coverage at 51% during the first 180 days after emergency use authorization, uptake was relatively low. We observed large disparities in vaccination by race and ethnicity for children in the NYC public school system. Asian children were most likely to be vaccinated and Black and White children least likely. However, controlling for student characteristics, neighborhood and school altered some of the disparities. For example, the Black-White disparity was virtually eliminated by the introduction of fixed effects for

Table 4
Predicted probabilities (in %) to be fully vaccinated at the end of the first 180 days of vaccine eligibility, stratified by age group, for children aged 5–18 in the New York City Student Population Health Registry.

	Age Group (years)		
	Age 5–11	Age 12–15	Age 16–18
	% (SE)	% (SE)	% (SE)
Overall	44.4	60.0	56.9
Sex			
Male *(ref.)*	44.1 (0.1)***	59.0 (0.1)***	54.9 (0.2)***
Female	44.7 (0.1)***	61.1 (0.1)***	59.0 (0.2)***
Race and ethnicity			
Asian	69.9 (0.2)***	81.8 (0.2)***	81.1 (0.4)***
Black	36.8 (0.2)***	48.2 (0.2)***	44.3 (0.4)***
Hispanic *(ref.)*	41.1 (0.1)	61.7 (0.2)	57.4 (0.3)
Other	45.9 (0.3)***	59.3 (0.5)***	57.5 (0.9)
White	36.8 (0.2)***	50.8 (0.3)***	50.4 (0.5)***
Ever enrolled in Medicaid			
Yes *(ref.)*	41.6 (0.1)	58.5 (0.1)	55.7 (0.2)
No	51.5 (0.1)***	65.2 (0.2)***	61.7 (0.4)***
Ever English language learner			
Yes *(ref.)*	43.3 (0.1)	59.1 (0.2)	54.7 (0.3)
No	44.7 (0.1)***	60.4 (0.1)***	58.0 (0.2)***
Model covariates			
Age Dummies	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes
R-squared	0.155	0.122	0.140
Observations	482,624	287,736	97,128

Notes: The table shows the predicted probability for each subgroup based on the estimated coefficients of the linear probability model of the probability of being fully vaccinated 180 days after the age of eligibility. The sample is stratified by students' age group. Results are then estimated using the full model with ordinary least squares on each stratified subsample. The full model includes sex, race and ethnicity, and age dummies, as well as student-level controls and neighborhood fixed effects. Hispanic was the referent group for race and ethnicity because it includes the largest number of students. Significance levels are calculated on the difference of the predicted probability for a particular subpopulation with respect to their group of reference. Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

neighborhood of residence and school attended, and the Asian percentage diminished. To be clear, in these specifications, we estimated the average disparities within neighborhoods (additionally, schools), rather than the disparities between neighborhoods which are reflected in the estimates from our baseline models. Our findings suggest much of the racial and ethnic group disparities were driven by differences between neighborhoods (and schools); these are differences that may have arisen from the effects of systemic, structural and institutional racism channeling resources unevenly across areas. (Centers for Disease Control and Prevention, n.d.) More generally, the results suggest neighborhood and school resources or characteristics could play important roles in reshaping disparities or facilitating improvements in equity.

There were significant differences in vaccination percentage by race and ethnicity across boroughs and different patterns emerging by age. White students' vaccination percentages were particularly related to geography, with White students living in Manhattan more than twice as likely to be vaccinated than White students in Staten Island or the Bronx. By age, differences by race and ethnicity were present though not as stark, while differences in timing were apparent by race and ethnicity and age. It is possible that, with additional time, disparities between these groups could show a reduction. However, future research should explore neighborhood and school resources as well as additional measures of vaccine "complacency, convenience, and confidence," factors which help to explain disparities in vaccine uptake more generally (MacDonald, 2015; Centers for Disease Control and Prevention, n.d.; Pulgaron et al., 2023).

This work is amongst the largest and most comprehensive analysis of child vaccination for COVID-19, particularly paying to attention to differences by race and ethnicity. It includes nearly the universe of children in the largest public school system in the nation and draws upon objective and comprehensive vaccination data. The racial and ethnic composition of the sample approximates that of all children in NYC according to census data, with a moderate underrepresentation of White children and overrepresentation of Black, Hispanic, and Asian children. (United States Census Bureau, 2019.) In comparison, all other published studies of disparities in children's COVID-19 vaccination rates rely on survey data, often with low response rates. However, we did not examine children who were not enrolled in public school (estimated at 14.9% of children in NYC) (New York City Department of Education, n.d.; United States Census Bureau, n.d.) which may hamper generalizability. Additionally, NYC experienced a reduction in public school enrollment in the COVID-19 period, though because we examine 180 days after eligibility this should not be a concern apart from generalizability. The administrative nature of the data means other factors that could be driving vaccination decisions (including preferences for vaccination) were not available, some of which are supported by surveys and polls.Finally, while we included type of insurance as a proxy, the absence of income data is a notable limitation. Our results are likely most readily generalized to other urban areas in the United States, with caution warranted in generalizing to low density, rural areas.

Important disparities across racial and ethnic groups in children's COVID-19 vaccination were apparent in NYC. Our work also showed that neighborhood context matters, likely in multiple ways. There were important differences in vaccination by the geographic unit of borough (similar to county), suggesting that disparities in vaccination rates are affected by social forces. At the same time, considering geography in a different way, many of the disparities by race/ethnicity were diminished when looking within a neighborhood. This implies that neighborhood demographics (e.g., average household income), neighborhood resources (e.g., access to vaccination) and the cultural attributes and preferences of those who live in a particular neighborhood (e.g., political persuasion, trust in science) could play a role in determining vaccination decisions. It is critical that future work understand such differences to determine how to appropriately target policies and programs to increase vaccine uptake.

CRediT authorship contribution statement

Brian Elbel: Conceptualization, Methodology, Writing – original draft, Formal analysis, Supervision, Funding acquisition. **Lloyd Heng:** Methodology, Validation, Formal analysis, Data curation, Writing – original draft, Visualization. **Kevin J. Konty:** Conceptualization, Data curation, Writing – review & editing, Supervision, Funding acquisition. **Sophia E. Day:** Conceptualization, Data curation, Writing – review & editing. **Michah W. Rothbart:** Conceptualization, Writing – review & editing. **Courtney Abrams:** Writing – original draft, Project administration. **David C. Lee:** Conceptualization, Writing – review & editing. **Lorna E. Thorpe:** Conceptualization, Writing – review & editing. **Amy Ellen Schwartz:** Conceptualization, Methodology, Writing – original draft, Formal analysis, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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