



A Neighborhood Analysis of Time Trends in COVID-19 Infection in NYC

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Abstract

To understand how observed COVID-19 diagnostic testing disparities across New York City (NYC) have impacted infection rates and COVID-19 spread, we examined neighborhood-level factors associated with, and the spatial distribution of, antibody test and infection rates, and compared changes over time by NYC ZIP code tabulation area (ZCTA). Data were obtained from 2019 American Community Survey 5-year estimates to create an SES index by ZCTA. Other predictors obtained from 2018 census data were the proportions of white residents, Hispanic residents and residents ≥ 65 years old. Multivariable Poisson regressions were performed to assess the rate of change for antibody testing and positivity, and to assess the independent associations with SES, race and age. Results: There was a significant association between the rate of antibody tests and SES quartiles (Q1: $\beta_{\text{adj}} = 0.04$, Q2: $\beta_{\text{adj}} = 0.03$ and Q3: $\beta_{\text{adj}} = -0.03$, compared to Q4), and the proportion of residents who are white ($\beta_{\text{adj}} = 0.004$, $p < .0001$), Hispanic ($\beta_{\text{adj}} = 0.001$, $p < .0001$), and ≥ 65 years ($\beta_{\text{adj}} = 0.01$, $p < .0001$). Total number of positive antibody tests was significantly inversely associated with SES quartile (Q1: $\beta_{\text{adj}} = 0.50$, Q2: $\beta_{\text{adj}} = 0.48$ and Q3: $\beta_{\text{adj}} = 0.29$, compared to Q4), and proportion of white residents ($\beta = -0.001$, $p < .0001$) and ≥ 65 years ($\beta = -0.02$, $p < .0001$), and significantly positively associated with proportion of Hispanic residents ($\beta = 0.003$, $p < .0001$). There are disparities in antibody testing and positivity, reflecting disproportionate impacts and undercounts of COVID-19 infection across NYC ZCTAs. Future public health response should increase testing in these vulnerable areas to diminish infection spread.

Keywords Coronavirus · Neighborhood characteristics · Socioeconomic conditions

Introduction

New York City (NYC) was an early and prominent epicenter of the Coronavirus (COVID-19) pandemic, with an estimated 10.8 % of residents (as of April 2021) having contracted COVID-19 [1]. Early in the pandemic, disparities in COVID-19 diagnostic testing and positivity were observed across the city [2]. Less wealthy, non-white areas accessed less testing but reported disproportionately higher case and positivity rates, indicating that tests were deployed inequitably and were not concentrated in areas of greatest need [2]. This suggests that testing was used as a diagnostic, rather

than preventive, tool in these neighborhoods. Over a year into the pandemic, the study of COVID-19 infection rates could be helpful to understand whether the documented social and racial disparities in diagnostic testing translated into more infections and a more rapid spread of the disease in under-tested areas, and to inform a swift and tailored public health response in the future.

NYC recently made data on antibody tests and positivity publicly available. Compared to COVID-19 diagnostic tests, which identify active infections and are useful for mitigating disease spread, antibody serology tests detect past infections, including those that may not have been confirmed by diagnostic testing, or may not have been clinically evident. Thus, they are a good proxy for the cumulative proportion of the population that ever had an infection.

Little is known about factors associated with the distribution of antibody tests and positivity, and testing trends over time across NYC. The primary objectives of this analysis were to (1) compare antibody positivity rates to COVID-19 case rates based on diagnostic testing, (2) assess the neighborhood-level factors associated with antibody test and

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positivity rates and (3) compare changes in antibody testing and positivity over time, across boroughs. The authors hypothesize that antibody testing and positivity trends are similar to that of diagnostic testing and positivity [2], with fewer tests and higher positivity in less wealthy neighborhoods and those with larger minority populations.

Methods

COVID-19 Diagnostic and Antibody Tests

Cumulative numbers of total and positive COVID-19 diagnostic tests were obtained from the NYC Department of Health's NYC Coronavirus data repository through January 28, 2021 [1]. Weekly total and positive antibody tests were obtained from the data repository from November 11, 2020, when the data first became publicly available, through January 28, 2021. This date was selected as a cutoff point in order to minimize potential misclassification of vaccine-produced antibodies as being due to infection, given the large uptick in COVID-19 vaccinations beginning the week of February 1, 2021 [1]. For both tests, modified zip code tabulation area (MODZCTA) cumulative testing and positivity rates for the full time period were calculated per 100,000 residents. For antibody testing, new weekly test and positivity rates, and positivity per test rate were also calculated, starting on November 19th, 2020, as numbers from the first release of data were cumulative through that point.

Covariates

A socio-economic status (SES) score for each Zip Code Tabulation Area (ZCTA) was defined, according to Lieberman-Cribbin et al. [2]. Although there are other established

SES scores, this one was selected as it was designed specifically around characteristics unique to NYC (e.g. less car/home ownership than other areas, independent of income). Median household income in the last 12 months, percent living below 150 % of the poverty line, median gross rent, education index, percent working class, percent unemployed, and > 1 occupant per room at the ZCTA level were obtained from the 2019 American Community Survey (ACS) 5-year estimates [3], which provide the most reliable data [4]. SES scores were divided into quartiles for each ZCTA, with 1 indicating low SES and 4 indicating high SES. The ZCTA proportion of residents who are white, Hispanic, and 65 years and older were obtained from 2018 census data [3]. As we were not interested in individual-level risk factors, only broad racial and ethnic composition groups were included as a proxy for access to resources. All data were converted to MODZCTA.

Statistical Analysis

The distributions of diagnostic and antibody testing were mapped according to MODZCTA using ArcGIS, v10.8. Associations between cumulative rates per 100,000 residents of COVID-19 diagnostic tests, COVID-19 positive diagnostic tests, antibody tests and antibody positive tests were assessed using Spearman correlations.

Antibody testing and positivity over time were examined by borough to assess how tests were accessed across the city. Multivariable Poisson regressions, with interactions between borough and time, were performed to compare changes over time, by NYC borough. Multivariable Poisson regressions were also performed to assess the independent associations of ZCTA level SES index, proportion of residents who are white, Hispanic, and ≥ 65 years with the number of total and positive antibody tests. The natural log of total population

Table 1 Distribution of cumulative antibody test rate and cumulative antibody positivity rate per 100,000 residents through January 28, 2021 and ZCTA level demographics, according to SES quartiles (1 = lowest SES; 4 = highest SES)

Variable	SES Score quartile			
	1 (n = 44)	2 (n = 44)	3 (n = 44)	4 (n = 45)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Antibody test rate per 100,000 residents	30091.36 (5773.34)	31157.47 (5964.56)	31900.50 (5064.29)	36386.19 (7311.61)
Positive antibody test rate per 100,000 residents	8819.81 (2683.71)	8545.82 (2649.56)	6810.06 (1367.31)	5416.62 (1283.40)
Proportion white (%)	27.76 (18.61)	37.03 (19.48)	51.07 (24.99)	68.56 (19.77)
Proportion Hispanic (%)	41.50 (22.83)	30.97 (18.19)	21.50 (11.61)	10.61 (5.01)
Proportion ≥ 65 years (%)	13.02 (4.80)	13.59 (3.45)	15.38 (4.24)	15.19 (6.77)

SES Index [2] included median household income in the last 12 months, median house value, percent below 150 % poverty, median gross rent, education index (weighted percentage of less than high school graduate, high school only and more than high school), percent working class, percent unemployed and > 1 occupant per room at the Zip Code Tabulation Area level, which were obtained from the 2019 American Community Survey (ACS) 5-year estimates [3]. Data for the proportion of White residents, the proportion of Hispanic residents, percent of the population 65 years and older in each ZCTA were obtained from 2018 census data. Cumulative antibody testing and positivity data through January 28, 2021 were obtained from the NYC Department of Health's NYC Coronavirus (COVID-19) data repository [1]

or total tests was used as an offset for modeling tests and positivity, respectively. All analyses were performed using SAS software, version 9.4 (SAS Institute, Cary, NC).

Results

Cumulative antibody test rate and positivity rate per 100,000 residents, and demographics according to SES quartiles are described in Table 1. The antibody test rates increased, while the antibody positivity decreased, with increasing SES. There was an uneven distribution of both diagnostic and antibody testing across NYC (Fig. 1).

We observed a statistically significant inverse correlation between COVID-19 diagnostic test rate and COVID-19 positive diagnostic test rate ($\rho = -0.44$ $p < .0001$), and statistically significant positive correlations between antibody test rate and antibody positive test rate ($\rho = 0.24$ $p = .0016$), COVID-19 diagnostic test rate and antibody test rate ($\rho =$

0.60 $p < .0001$), and COVID-19 positive diagnostic test rate and antibody positive test rate ($\rho = 0.50$ $p < .0001$) (Fig. 2).

Time Trends

There was a steady increase in all boroughs in weekly antibody positivity and positivity per testing rate by MODZCTA, but especially in Brooklyn and Queens (Fig. 3). Since November 11, 2020, the rates of antibody testing and positivity generally rose, but both increased the fastest in Staten Island (Fig. 3). As of November 19, 2020, there were significantly more antibody tests in the Bronx ($\beta = 0.37$), Brooklyn ($\beta = 0.31$), Manhattan ($\beta = 0.56$) and Queens ($\beta = 0.34$), compared to Staten Island (Table 2a), with the fastest increase in Staten Island, and slowest in the Bronx ($\beta_{\text{interaction}} = -0.21$). There was a slight decrease in Manhattan ($\beta_{\text{interaction}} = -0.28$). During the same period, there was significantly higher antibody positivity in the Bronx ($\beta = 0.56$), compared to Staten Island (Table 2a). Positivity increased over time in all boroughs, with the fastest increase

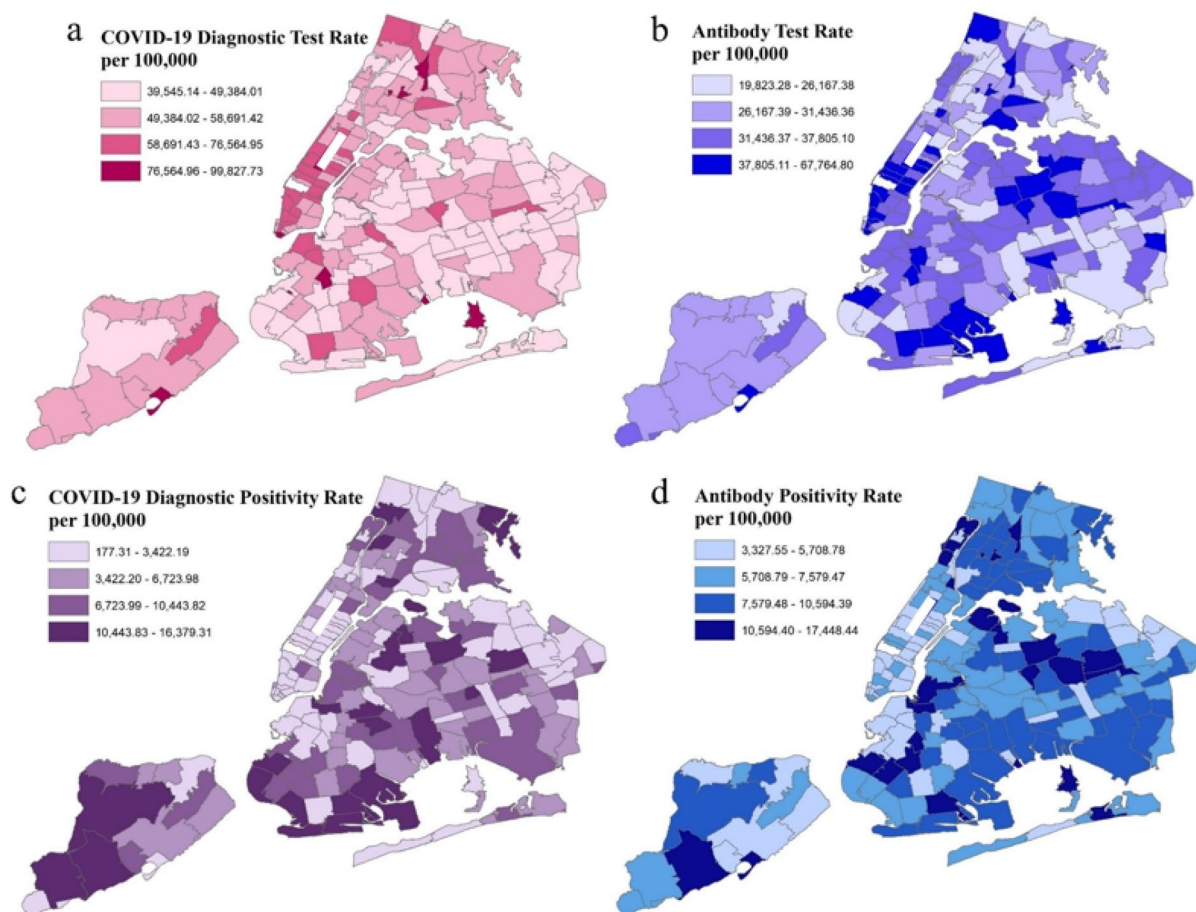


Fig. 1 Spatial distribution of COVID-19 diagnostic test rate (a), antibody test rate (b), COVID-19 diagnostic positivity rate (c) and antibody test positivity rate (d), all per 100,000 residents. Cumula-

tive COVID-19 diagnostic test and positivity rates from February 29, 2020 through January 28, 2021 [1]. Cumulative antibody test and positivity rates through January 28, 2021 [1]

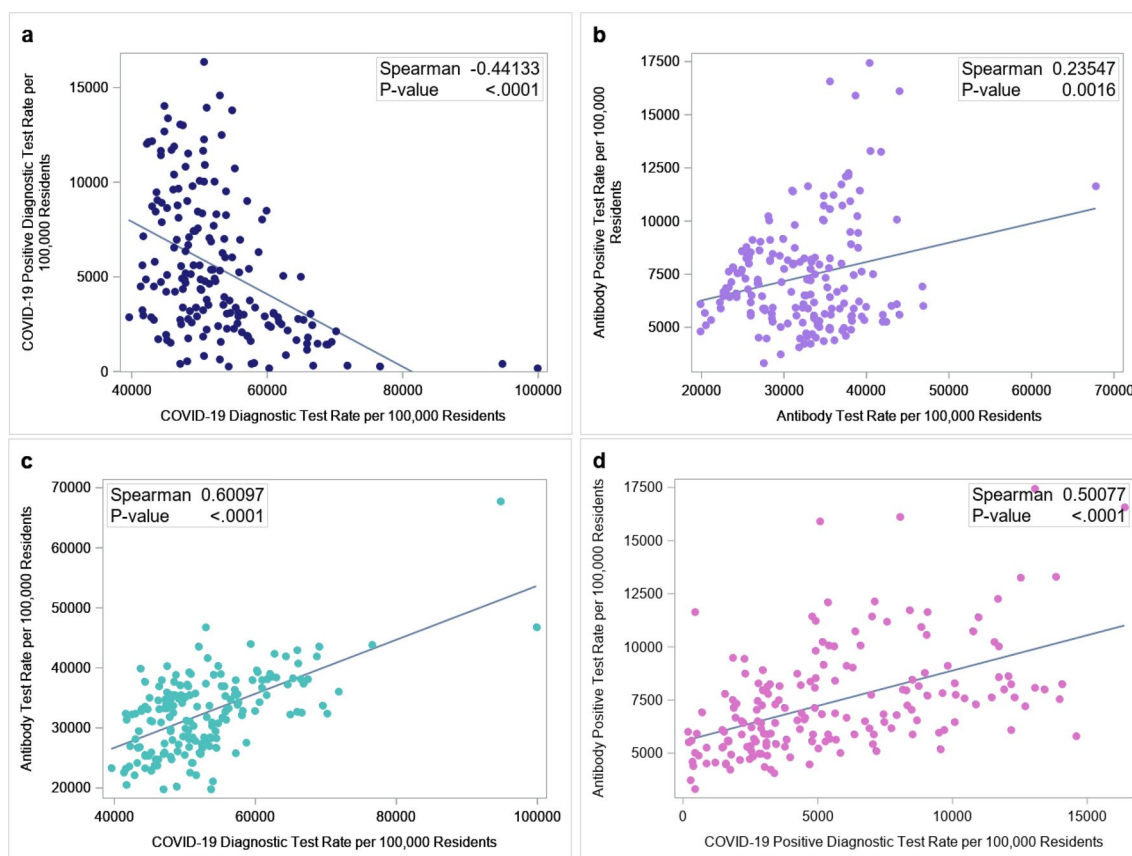


Fig. 2 Spearman correlations to assess the association between COVID-19 diagnostic test rate and COVID-19 positive diagnostic test rate (a), antibody test rate and antibody positive test rate (b), COVID-

19 diagnostic test rate and antibody test rate (c), and COVID-19 positive diagnostic test rate and antibody positive test rate (d), all cumulative through January 28, 2021 by MODZCTA per 100,000 residents

in Staten Island, and the slowest in the Bronx ($\beta_{\text{interaction}} = -0.24$).

Predictors of Antibody Tests and Positivity

In the multivariable model, there was a significant association between the cumulative number of antibody tests and SES score quartiles (Q1: $\beta_{\text{adj}} = 0.04$, Q2: $\beta_{\text{adj}} = 0.03$ and Q3: $\beta_{\text{adj}} = -0.03$, compared to Q4). There was a significant positive association between antibody tests and the MODZCTA proportion of residents who are white ($\beta_{\text{adj}} = 0.004$, SE = 0, $p < .0001$), Hispanic ($\beta_{\text{adj}} = 0.001$, SE = 0, $p < .0001$) and ≥ 65 years ($\beta_{\text{adj}} = 0.01$, SE = 0.0002, $p < .0001$). Positive antibody tests were significantly inversely associated with SES scores quartile (Q1: $\beta_{\text{adj}} = 0.50$, Q2: $\beta_{\text{adj}} = 0.48$ and Q3: $\beta_{\text{adj}} = 0.29$, compared to Q4), proportion of residents who are white ($\beta = -0.001$, SE = 0.0001, $p < .0001$) and ≥ 65 years ($\beta = -0.02$, SE = 0.0003, $p < .0001$), and significantly positively associated with the proportion of Hispanic residents ($\beta = 0.003$, SE = 0.0001, $p < .0001$) (Table 2b).

Discussion

To our knowledge, this is the first analysis to use NYC data to examine the neighborhood level sociodemographic factors associated with antibody test and positivity rates, offering a first in-depth look at the distribution of infection in the city. These results indicate that while fewer tests were performed in areas with a higher proportion of non-white residents, the proportion of positive tests was highest in these areas, in addition to areas with lower SES scores. These findings mirror the disparities observed for COVID-19 diagnostic testing and positivity, in that less wealthy neighborhoods experienced less testing coupled with more positivity and higher case rates. These disparities also correlate with risk factors for COVID-19 infection, including complications from COVID-19 [5], such as higher rates of chronic health conditions, as well as limited ability to work remotely and more crowded housing, both of which limit one's ability to follow public health guidelines of social distancing and staying home. These results demonstrate that we continue to consistently under-measure in areas of greatest need, identified by both heavy COVID-19 caseloads, and populations at

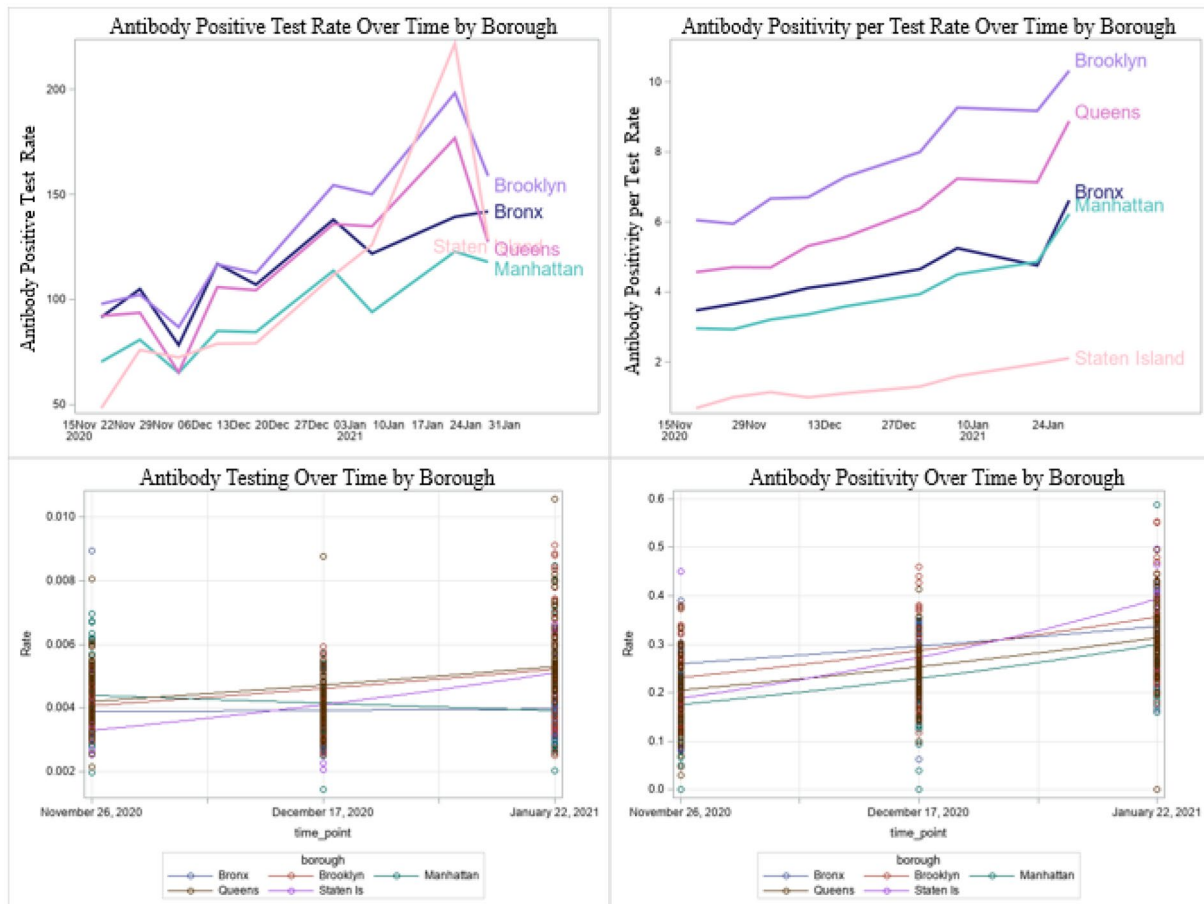


Fig. 3 Antibody positivity over time by MODZCTA, accounting for both the population (a) and test rate per 100,000 residents (b), change over time for antibody testing (c) and antibody positivity (d) by borough in New York City

greater risk of severe disease. The changes in testing rates and positivity over time according to borough suggest that the spread of COVID-19 was rapid and uneven, and that access to and use of antibody testing was disproportionate to the borough-specific caseload. All boroughs experienced steady increases in new or existing infections, but the Bronx and Manhattan observed slower increases in antibody testing over time.

Further, our findings indicate that, despite the fact that cases identified by COVID-19 diagnostic test rates and antibody test rates are positively correlated, the positive antibody test rates are significantly higher than the COVID-19 positive test rates per 100,000 residents, in many cases. This clearly suggests that there are likely more people who were infected than were identified by diagnostic testing, likely including a large number of asymptomatic infections that originally went unidentified. However, this is not surprising, as due to the shortage of tests early in the pandemic, NYC was actively discouraging people from getting tested unless presenting with severe symptoms [6]. In addition, as antibody tests identify past infections, they may be more

indicative of want or access, so the true number is likely even higher. For example, antibody testing might be useful for someone experiencing persistent symptoms (i.e., “long COVID”) or to determine eligibility for plasma donation. Unlike COVID-19 diagnostic tests which are widely advertised, free in NYC, and require only a nasopharyngeal swab, antibody tests may be inaccessible, have an associated cost and require a finger prick or blood draw.

A major strength of this analysis is that we utilized data from the critical window of time before COVID-19 vaccination was widespread. Examining disparities in diagnostic testing and cumulative antibody positivity can help provide insight about areas where public health messaging has been ineffective and areas that have a higher risk of COVID-19 infection and severity so strategies can be implemented to ensure that COVID-19 vaccinations are effectively deployed into these most-at-risk areas. The approach taken here can be translated to other respiratory diseases as well, which can be helpful to identify areas that are traditionally under-surveilled and may be most at risk for future outbreaks.

Table 2 Change over time in number of antibody tests and positive tests, by borough (a) and zip code level predictors of cumulative number of antibody tests and positive tests (b) through January 28, 2021

Outcome	Total tests ^a		Total Positivity ^b	
	β_{adj} (SE)	p-value	β_{adj} (SE)	p-value
a				
Intercept	− 5.93 (0.08)	< 0.0001	− 2.03 (0.22)	< 0.0001
Bronx	0.37 (0.09)	< 0.0001	0.56 (0.22)	0.0119
Brooklyn	0.31 (0.09)	0.0004	0.36 (0.23)	0.1234
Manhattan	0.56 (0.09)	< 0.0001	0.03 (0.23)	0.8936
Queens	0.34 (0.09)	0.0002	0.24 (0.23)	0.2907
Staten Island	0 (ref.)	–	0 (ref.)	–
Time	0.22 (0.04)	< 0.0001	0.37 (0.08)	< 0.0001
Time * Bronx	− 0.21 (0.04)	< 0.0001	− 0.24 (0.08)	0.0035
Time * Brooklyn	− 0.09 (0.04)	0.0332	− 0.15 (0.08)	0.0727
Time * Manhattan	− 0.28 (0.04)	< 0.0001	− 0.10 (0.08)	0.2218
Time * Queens	− 0.10 (0.04)	0.0139	− 0.16 (0.08)	0.0583
Time * Staten Island	0 (ref.)	–	0 (ref.)	–
b				
Intercept	− 1.48 (0.004)	< 0.0001	− 1.54 (0.008)	< 0.0001
SES ^c Quartile 1	0.04 (0.002)	< 0.0001	0.50 (0.005)	< 0.0001
SES Quartile 2	0.03 (0.002)	< 0.0001	0.48 (0.005)	< 0.0001
SES Quartile 3	− 0.03 (0.002)	< 0.0001	0.29 (0.005)	< 0.0001
SES Quartile 4	0.0 (ref.)	.	0.0 (ref.)	.
Proportion White residents (%)	0.004 (0)	< 0.0001	− 0.001 (0.0001)	< 0.0001
Proportion Hispanic residents (%)	0.001 (0)	< 0.0001	0.003 (0.0001)	< 0.0001
Proportion age ≥ 65 years (%)	0.01 (0.0002)	< 0.0001	− 0.02 (0.0003)	< 0.0001

Models were adjusted for all variables in this table. SE: standard error

^aA poisson regression was performed using log(ZCTA population) as an offset

^bA poisson regression was performed using log(total tests) as an offset

^cSES Index [2] included median household income in the last 12 months, median house value, percent below 150 % poverty, median gross rent, education index (weighted percentage of less than high school graduate, high school only and more than high school), percent working class, percent unemployed and > 1 occupant per room at the Zip Code Tabulation Area level, which were obtained from the 2019 American Community Survey (ACS) 5-year estimates [3]. Data for the proportion of White residents, the proportion of Hispanic residents, percent of the population 65 years and older were obtained from 2018 census data

Limitations

As this analysis is ecological in nature and results are based on neighborhood-level data, we are not able to draw individual-level conclusions. It is possible that testing and positivity are influenced by individual-level factors that could not be captured by the data used in our analysis. Another limitation is that antibody data only recently became publicly available in November 2020; trends from the beginning of the pandemic could not be analyzed here. Likewise, more recent data would likely include antibodies produced by COVID-19 vaccinations, not only those produced by infections. However, antibody testing up until the cut-off point captures antibodies measured from the start of the pandemic and therefore can still inform where antibody testing and infections were concentrated. We also do not know when people were infected with COVID-19 or the specific time frame for antibody tests prior to November, 2020, and therefore cannot

correct for any delays in reporting. Additionally, as it takes a few weeks to develop enough antibodies to be detected by the serology test, it is possible that some infected people had false-negative results by testing too soon after infection; false-positive results are also worth noting. However, according to a recent FDA performance analysis, the sensitivity/positive predictive values (PPV) and specificity/negative predictive values (NPV) of all antibody IgG tests were very high [7]. Finally, it is not known how long antibodies last after infection, so it is possible that some people who had COVID-19 tested negative for antibodies. We believe this is unlikely to have biased our results, as we expect the distribution of such cases to be random, but this means that we are likely still undercounting the true cumulative number of COVID-19 cases in NYC. It is also worth noting that antibody testing may have decreased due to increased focus on COVID-19 vaccinations and conversion of testing sites to vaccination sites, possibly contributing to undercounts.

However, our analysis minimized this effect by limiting the analysis to a time frame before vaccination efforts ramped up in NYC.

Conclusions

Understanding the landscape of testing and positivity can inform how public health prevention and mitigation efforts are deployed for future epidemic responses. This analysis confirms that patterns of antibody testing and positivity follow a similar pattern of disparities to that found with diagnostic testing and positivity, reinforcing the necessity of extensive testing across all neighborhoods of NYC, but especially in areas with populations most vulnerable to severe complications from infection. Future analyses should focus on needs-based assessments to explore any barriers to testing access for underserved populations. Preventing future spread of infections should start with increased concentration of testing in under-surveilled areas, including those with large non-white populations and less wealth.

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Data Availability All data used for analysis in this study are publicly available at the following sites: 1. NYC Department of Health Coronavirus Data Repository at <https://github.com/nychealth/coronavirus-data>.

2. U.S. Census Bureau 2019 American Community Survey 5-Year estimates at <https://data.census.gov/cedsci>.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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