The prevalence of SARS-CoV-2 infection and long COVID in U.S. adults during the BA.4/BA.5 surge, June–July 2022

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ABSTRACT

Due to changes in SARS-CoV-2 testing practices, passive case-based surveillance may be an increasingly unreliable indicator for monitoring the burden of SARS-CoV-2, especially during surges.

We conducted a cross-sectional survey of a population-representative sample of 3042 U.S. adults between June 30 and July 2, 2022, during the Omicron BA.4/BA.5 surge. Respondents were asked about SARS-CoV-2 testing and outcomes, COVID-like symptoms, contact with cases, and experience with prolonged COVID-19 symptoms following prior infection. We estimated the weighted age and sex-standardized SARS-CoV-2 prevalence, during the 14-day period preceding the interview. We estimated age and gender adjusted prevalence ratios (aPR) for current SARS-CoV-2 infection using a log-binomial regression model.

An estimated 17.3% (95% CI 14.9, 19.8) of respondents had SARS-CoV-2 infection during the two-week study period–equating to 44 million cases as compared to 1.8 million per the CDC during the same time period. SARS-CoV-2 prevalence was higher among those 18–24 years old (aPR 2.2, 95% CI 1.8, 2.7) and among non-Hispanic Black (aPR 1.7, 95% CI 1.4,2.2) and Hispanic adults (aPR 2.4, 95% CI 2.0, 2.9). SARS-CoV-2 prevalence was also higher among those with lower income (aPR 1.9, 95% CI 1.5, 2.3), lower education (aPR 3.7 95% CI 3.0,4.7), and those with comorbidities (aPR 1.6, 95% CI 1.4, 2.0). An estimated 21.5% (95% CI 18.2, 24.7) of respondents with a SARS-CoV-2 infection >4 weeks prior reported long COVID symptoms.

The inequitable distribution of SARS-CoV-2 prevalence during the BA.4/BA.5 surge will likely drive inequities in the future burden of long COVID.

1. Introduction

The COVID-19 pandemic continues to cause significant morbidity and mortality both in the United States (U.S.) and globally. While vaccines and boosters against SARS-CoV-2 have shown dramatic effectiveness in reducing COVID-19 hospitalizations and deaths,(Link-Gelles et al., 2022) the circulation of more transmissible SARS-CoV-2 subvariants and waning immunity underscores the importance of continued monitoring of SARS-CoV-2 burden. At the writing of this report (August 2022), BA.4/BA.5 is the predominant subvariant circulating in the U.S[2]. Given the dynamic and uncertain nature of the virus at this time it is imperative that useful, robust, and proactive SARS-CoV-2 monitoring systems be maintained to characterize both short- and long-term sequelae of the pandemic (i.e., long COVID).

While the virus and its impact have evolved substantially, the current approaches to COVID-19 public health surveillance in the U.S. has not evolved to keep pace, making tracking of the true burden of SARS-CoV-2 increasingly challenging. Declines in SARS-CoV-2 screening and diagnostic testing combined with the increased use of at-home rapid antigen tests(Rader et al., 2022) (which are not generally captured via routine case-based surveillance), are likely resulting in an increasing underestimation of the true burden of infection.(Dean, 2022) Low rates of laboratory testing driven primarily by symptoms, exposure, or a positive at-home test results may also inflate test positivity rates reported by testing sites relative to those in the general population.(Walgreens COVID-19 index, n.d.) In addition, the extent of incomplete reporting of positive tests at local, state, and national level are yet to be evaluated. Case data from passive case-based surveillance reflect a non-

representative sample of individuals who present for testing(Sherratt et al., 1829) which further complicates the interpretation of trends in case numbers. Population-based surveys can, therefore, complement both routinely collected case-based data to inform public health mitigation measures.(Coronavirus (COVID-19) Infection Survey: methods and further information, n.d.)

The high exposure to transmissible sub-variants is also likely to contribute to a growing number of individuals currently experiencing long COVID. Long COVID, or the recurring or ongoing symptoms or clinical findings four or more weeks after SARS-CoV-2 infection is likely affecting millions of Americans. Recent estimates from the Centers for Disease Control and Prevention (CDC) show that at least 1 in 5 adults with prior SARS-CoV-2 infection experience long COVID(Bull-Otterson et al., 2022).

There are currently only a few published studies(Long COVID, n.d.; Perlis et al., 2022) from the U.S. measuring current infections and combining individual-level information on demographics, prior infection history, vaccination status, long COVID, education status, and income. Using a population-representative survey, this study aimed to estimate the prevalence of SARS-CoV-2, characterize factors associated with testing and infection, and estimate the prevalence of long COVID among U.S. adults with a prior SARS-CoV-2 infection.

2. Methods

2.1. Survey-based estimation of SARS-CoV-2 prevalence

We conducted a cross-sectional survey, in English and Spanish, between June 30 and July 2, 2022, of 3042 adult U.S. residents via landlines (IVR) and mobile phones (SMS text). Potential participants were randomly selected from a sampling frame of U.S adults. To create weights representative of the U.S.-population 18 years or older, we used an iterative weighting method, raking, to marginal proportions of race, ethnicity, age, self-identified sex, and education by U.S. region based on the 2020 U.S. census.(United States Census Bureau, n.d.) Further details on the survey design, sampling and weighting are provided in Appendix 1.

The survey questionnaire (Appendix 2) ascertained SARS-CoV-2 testing results of viral PCR, rapid antigen and/or at-home rapid diagnostic tests taken in the 14 days prior to the survey (June 16–July 2). During the same time period, the BA.4/BA.5 Omicron subvariant rose from an estimated 40% of reported cases to 71%.(CDC, 2020a, b) The survey captured information on COVID-19 symptoms, as well as known close contacts with a confirmed or probable case of SARS-CoV-2 infection. COVID-19 symptoms included any of the following: fever of ≥100 °F, cough, runny nose and/or nasal congestion, shortness of breath, sore throat, fatigue, muscle/body aches, headaches, loss of smell/taste, nausea, vomiting and/or diarrhea.(CSTE Interim Position Statement: Update to COVID-19 Case Definition - Council of State and Territorial Epidemiologists, n.d.) Participants were also asked about vaccination status (but not manufacturer or date(s) of vaccination), comorbidities that increase vulnerability to severe COVID-19, and prior history of SARS-CoV-2 infection/COVID. Respondents were classified as vulnerable if they above the age of 65 years, had more than one reported comorbidity, or were unvaccinated,(Robertson et al., 2022) all of which were conditions or exposures that CDC had identified in March 2020 as increasing the risk for COVID-19 complications.

2.2. Point prevalence estimation

Consistent with previous studies(Qasmieh et al., 2022a, b) we calculate prevalence using information reported by respondents to estimate the number and proportion of respondents who likely had SARS-CoV-2 infection during the study period based on the following mutually exclusive, hierarchical case classification: 1) Confirmed case: self-report of one or more positive tests with a health care or testing provider; 2)

Probable case: self-report of a positive test result exclusively on at-home rapid tests (i.e. those that were not followed up with confirmatory diagnostic testing with a provider); or 3) Possible case: self-report of COVID-like symptoms AND a known epidemiologic link (close contact) to one or more laboratory confirmed or probable (symptomatic) SARS-CoV-2 case(s)(CSTE Interim Position Statement: Update to COVID-19 Case Definition - Council of State and Territorial Epidemiologists, n.d.) in a respondent who reported never testing or only testing negative during the study period.

2.3. The intersection of vaccine- and infection-induced immunity

We combined self-reported vaccination status along with self-reported prior COVID infections (as of June 15, 2022) to create four SARS-CoV-2 immunity categories. Respondents who were fully vaccinated and those who were also boosted at least once (fully vaccinated/boosted) with a history of prior COVID were classified as having 'hybrid immunity' against severe COVID; those who were fully vaccinated or boosted at least once with no history of prior COVID were classified as having 'vaccine-induced immunity only'; those who were not fully vaccinated but had a history or prior COVID were classified as having 'infection-induced immunity only'; and those who were neither vaccinated/boosted nor had a history of COVID were classified as having 'no prior SARS-CoV-2 immunity' (SARS-CoV-2 naive).

2.4. Long COVID definition

We used a question routinely used by the Office of National Statistics in the United Kingdom to define and assess the burden of long COVID[7]. Respondents in our survey who reported a history of prior COVID were asked "Would you describe yourself as having 'long COVID', that is you experienced symptoms such as fatigue, difficulty concentrating, shortness of breath more than 4 weeks after you first had COVID-19 that are not explained by something else?". The point prevalence of long COVID was estimated among those with prior SARS-CoV-2 infection as the proportion responding affirmatively. Respondents whose most recent SARS-CoV-2 infection was within the past 4 weeks were classified as not having long COVID, to avoid conflation of symptoms of acute illness, and to align with the definition of long COVID, which was assessed more than four weeks after infections.

2.5. SARS-CoV-2 routine testing and case surveillance data

We used publicly available, daily aggregated data on the number of SARS-CoV-2 diagnostic tests and positive results through July 2, 2022, (CDC, n.d.-b) to ascertain the number of tests and number positives reported to the CDC during the study period.

2.6. Statistical analysis

We estimated the prevalence of SARS-CoV-2 and long COVID by socio-demographic characteristics, region, vaccination status, comorbidity, and prior COVID-19 status. Survey weights were applied to generate population-representative numbers and estimates of the proportion who were SARS-CoV-2 positive at any time during the study period along with 95% confidence interval (95% CI). We applied these weighted sample proportions and 95% CIs to the 254,297,978 U.S. residents ≥18 years to obtain estimates of the absolute number of adults with SARS-CoV-2 infection and long COVID. Pearson's chi-squared test was performed to assess associations between respondent characteristics and testing status. We used direct standardization to calculate age and sex adjusted prevalence estimates using the U.S. 2020 Census. Crude and age- and gender-adjusted prevalence ratios and 95% CIs were calculated using a log-binomial model. We used sex for standardization and gender for adjustment since our survey captured only gender. For standardization, we had to assume that reported gender was reported sex.

The study protocol was approved by the Institutional Review Board at the City University of New York (CUNY IRB 2022–0407).

3. Results

3.1. Prevalence

The weighted characteristics of survey participants are shown in Table 1. We estimate that 17.3% (95% CI 14.9, 19.8) of the approximately 254,297,978 million U.S. adults had SARS-CoV-2 between 16-June and 2-July 2022, which corresponds to about 43,993,550 adults (95% CI 37,890,399 - 50,351,000). During the same time period, 1,805,033 cases were reported to CDC. The SARS-CoV-2 prevalence estimate of 17.3% includes: 1) 10.0% (95% CI 7.6, 12.3) of respondents who tested positive based on one or more tests with a healthcare or testing provider, 2) 4.8% (95% CI 3.8, 5.7) who were positive exclusively based on one or more at-home rapid tests; and 3) 2.6% (95% CI 1.8, 3.4) who met the definition for possible SARS-CoV-2 infection. The test positivity rate among those who tested with a healthcare or testing provider was 33.9% (95% CI 27.6, 40.1). Among respondents who tested positive on any diagnostic test, 52.2% were symptomatic and 47.8% were asymptomatic.

Sex-standardized SARS-CoV-2 prevalence was higher among 18–24-year-olds (41.3%, 95% CI 32.7, 50.4), while age-standardized prevalence was higher among males (22.9%, 95% CI 19.3, 26.9). Age- and sex-standardized prevalence was higher among Hispanic adults (25.8%, 95% CI 19.5, 33.3), and adults with HS education level or below (41.1%, 95% CI 30.4, 52.6). Age- and sex-standardized prevalence was also higher among adults in the lowest category of annual household income below $20,000 (28.2%, 95% CI 22.9, 34.1). Regional differences in prevalence were also observed, with higher standardized prevalence reported in the West region of the U.S. (21.9%, 95% CI 17.4, 27.0), followed by the Northeast region (19.7%, 95% CI 15.8, 24.3).

3.2. Protection against severe disease

Among the 32.4% of those who were either vaccinated/boosted and who also had SARS-CoV-2 infection in the past (hybrid immunity), the age- and sex-standardized prevalence was 29.2% (95% CI 25.2, 33.3). Among the 36.1% respondents with vaccine-induced immunity but not immunity from a prior SARS-CoV-2 infection in the past, SARS-CoV-2 prevalence was 8.3% (95% CI 6.0, 11.6). Among the 16.5% who have infection-induced immunity but were never vaccinate, SARS-CoV-2 prevalence was 17.0% (95% CI 12.4, 22.8) and prevalence was 5.8% (95% CI 3.2, 10.2) among respondents who were neither vaccinated/boosted nor had prior SARS-CoV-2 infection (15.0%).

3.3. Vulnerability to severe COVID-19

The estimated prevalence of SARS-CoV-2 was 11.9% (95% CI 8.7, 15.9) among unvaccinated, 10.7% (95% CI 8.8, 12.9) among those 65 years or older, and 28.8% (95% CI 24.8, 33.2) among respondents who reported a comorbidity. Among those with any of these vulnerabilities to severe COVID-19 (age ≥ 65, comorbidities, unvaccinated), 19.6% (95% CI 16.9, 22.5) had SARS-CoV-2 infection.

3.4. Testing

Just under half (42.2%) of the adults in our sample reported receiving any SARS-CoV-2 test during the study period. About 2.2% of the sample reported testing with a health or testing provider only, 12.3% tested exclusively using an at-home rapid antigen test, and 27.3% tested both with a provider and at home. Differences were observed between testers and non-testers (Table 2) with testers more likely to be between 18 and 24 years old, and less likely to be above 55 years old. Testers were more likely to be Hispanic (22.1%), have less than a HS degree

(19.7%), be employed (52.5%) and live in the Northeast region (21.0%). Testers were also more likely to have received a booster (62.3%) and have hybrid immunity (45.6%).

3.5. Long COVID

Among respondents who had prior SARS-CoV-2 who also reported their most recent SARS-CoV-2 infection was >4 weeks prior to the survey (34.1% or 86,503,616 U.S. adults), an estimated 21.5% (95% CI 18.2, 24.7) reported long COVID symptoms (Table 3). Long COVID prevalence estimates varied across socio-demographic characteristics. Sex-standardized prevalence of long COVID was higher among respondents who were aged 35–44 (27.6%, 95% CI 19.3, 37.8), and age-standardized prevalence of long COVID was higher among female (27.4%, 95% CI 22.8, 32.6). Age- and sex-standardized prevalence of long COVID was higher among respondents who were Black non-Hispanic (27.3%, 95% CI 17.0, 41.0), unemployed (27.5%, 95% CI 20.6, 35.7) or had comorbidities (32.8%, 95% CI 25.9, 40.5). The standardized prevalence of long COVID was lower among respondents that were 65+ (14.8%, 95% CI 10.8, 19.9), male (15.5%, 95% CI 11.9, 20.2), or uninsured (14.0, 95% CI 7.7, 20.3).

In age- and gender-adjusted models, we observed a higher prevalence of long COVID for females (versus male) (aPR: 1.8, 95% CI 1.4, 2.3), those with (versus without) comorbidities (aPR: 1.8, 95% CI 1.4, 2.3), and those who were insured (versus not or unknown) (aPR: 1.9, 95% CI 1.3, 2.7). Compared to those who were currently boosted, we did not find statistically significant differences in prevalence of long COVID among those who were fully vaccinated but not boosted (aPR: 1.2, 95% CI 0.9, 1.6) and those who were not vaccinated (aPR: 1.1, 95% CI 0.8, 1.4) (see Table 3).

4. Discussion

We observed that 17.3% of adults in the U.S., or approximately 44.0 million adults, had SARS-CoV-2 infection during the two-week study period during the BA.4/BA.5 surge in late June and early July 2022, much more than cases detected by case-based surveillance. This was at a time when the more transmissible BA.4/BA.5 subvariant made up an estimated 57% of all cases in the week ending July 2, 2022.(CDC, n.d.-a) Importantly, there were major disparities in SARS-CoV-2 prevalence along the lines of social determinants of health, underscoring the longstanding inequities in SARS-CoV-2 burden in the US. Additionally, an estimated 18.6 million of the 86.5 million adults in the U.S. who reported having had SARS-CoV-2 at least once 4 or more weeks prior to the survey reported lingering symptoms consistent with long COVID. Disparities in SARS-CoV-2 infection during the 2-week period of our study portend a major contribution to subsequent disparities in long COVID burden. Our study provides important context to both the true burden of SARS-CoV-2 and its epidemiologic, sociodemographic, and geographic distribution.

Between June 16–July 2, 1,805,033 SARS-CoV-2 cases were reported to CDC. Our estimate of 44 million adults with SARS-CoV-2 infection during the same period is significantly higher (24-fold) than the official CDC case count. Our percent positivity rate based on combined PCR and rapid antigen tests (33.9%) was also higher than CDC positivity rate (19.1%). Differences between estimates are in part due to CDC reporting 'confirmed' cases based on positive cases from nucleic acid amplification tests (NAAT) and not rapid antigen tests (Jones et al., 2022). Our study underscores the extent to which reliance only on confirmed and reported cases contribute to the vast underestimation of the true burden of infection during surges. The degree of underestimation is likely increasing with time.(Dean, 2022; Shircliff et al., n.d.) A few studies have examined the performance of case-based passive surveillance for SARS-CoV-2(Gold et al., 2021; Simpson et al., 2022) but a broader evaluation of SARS-CoV-2 surveillance systems in relation to current public health goals(Nash and Geng, 2020) is important.

Table 1
SARS-CoV-2 point prevalence among U.S. adults across key characteristics, June 16 - July 2, 2022.

	Total	SARS-CoV-2 cases	Crude prevalence of SARS-CoV-2 infection‡	Age and sex direct-standardized prevalence of SARS-CoV-2 infection**	Crude prevalence ratio (PR)	Adjusted prevalence ratio (aPR)***
	N (%)	No. (%)	% (95% CI)	% (95% CI)	PR (95% CI)	aPR (95% CI)
Total	3042 (100%)	527 (100%)	17.3 (14.9, 19.8)			
Case classification						
Confirmed		303 (10.0)	10.0 (7.6, 12.3)			
Probable		145 (4.8)	4.8 (3.8, 5.7)			
Possible cases (non-testers/ negatives)		79 (2.6)	2.6 (1.8, 3.4)			
Age						
18–24	365 (12.0)	161 (30.5)	44.1 (32.5, 55.6)	41.3 (32.7, 50.4)	2.3 (1.9, 2.8)	2.2 (1.8, 2.7)
25–34	547 (18.0)	105 (19.8)	19.1 (13.2, 25.1)	20.3 (14.4, 27.7)	Ref	Ref
35–44	495 (16.3)	79 (14.9)	15.9 (10.5, 21.2)	15.6 (10.8, 21.9)	0.8 (0.6, 1.1)	0.8 (0.6, 1.0)
45–54	498 (16.4)	63 (11.9)	12.6 (8.0, 17.2)	12.4 (8.4, 18.0)	0.7 (0.5, 0.9)	0.6 (0.5, 0.8)
55–64	508 (16.7)	52 (9.8)	10.2 (7.4, 12.9)	10.3 (7.8, 13.4)	0.5 (0.4, 0.7)	0.5 (0.4, 0.7)
65+	629 (20.7)	69 (13.1)	11.0 (8.9, 13.0)	10.7 (8.8, 12.9)	0.6 (0.4, 0.8)	0.5 (0.4, 0.7)
Gender						
Male	1443 (47.5)	321 (60.9)	22.2 (17.9, 26.6)	22.9 (19.3, 26.9)	1.8 (1.5, 2.1)	1.9 (1.6, 2.2)
Female	1516 (50.0)	185 (35.1)	12.2 (9.9, 14.5)	12.2 (10.1, 14.7)	Ref	Ref
Non-binary	82 (2.7)	21 (4.0)	25.5 (12.1, 38.9)	22.7 (13.8, 35.1)	2.1 (1.4, 3.1)	1.5 (1.0, 2.2)
Race/ethnicity						
Black NH	350 (11.5)	86 (16.3)	24.5 (17.6, 31.4)	22.7 (17.4, 29.2)	2.1 (1.7, 2.7)	1.7 (1.4, 2.2)
White NH	1794 (59.0)	206 (39.1)	11.5 (9.9, 13.1)	11.9 (10.0, 14.0)	Ref	Ref
Hispanic	460 (15.1)	172 (32.6)	37.4 (27.0, 47.7)	25.8 (19.5, 33.3)	3.3 (2.7, 3.9)	2.4 (2.0, 2.9)
Asian/Pacific islander	171 (5.6)	34 (6.4)	19.7 (5.5, 33.9)	16.3 (8.3, 29.5)	1.7 (1.2, 2.4)	1.1 (0.8, 1.5)
Other	268 (8.8)	30 (5.6)	11.1 (5.2, 16.9)	9.7 (5.3, 17.2)	1.0 (0.7, 1.4)	0.8 (0.6, 1.2)
Years of education						
Some HS and below	353 (11.6)	194 (36.9)	55.1 (43.4, 66.8)	41.1 (30.4, 52.6)	4.9 (4.0, 6.1)	3.7 (3.0, 4.7)
HS grad	830 (27.3)	94 (17.4)	11.3 (8.2, 14.3)	11.7 (8.7, 15.4)	Ref	Ref
Some college	934 (30.7)	112 (21.2)	12.0 (9.3, 14.7)	12.2 (9.5, 15.5)	1.1 (0.8, 1.4)	1.0 (0.8, 1.4)
College grad and above	925 (30.4)	127 (24.2)	13.8 (11.4, 16.2)	14.5 (11.9, 17.5)	1.2 (1.0, 1.6)	1.2 (1.0, 1.6)
Household income						
Below 20 K	561 (18.4)	187 (35.6)	33.4 (24.6, 42.2)	28.2 (22.9, 34.1)	2.3 (1.9, 3.0)	1.9 (1.5, 2.3)
20,000 - 60,000	941 (31.0)	124 (23.6)	13.2 (9.9, 16.5)	12.7 (9.9, 16.1)	0.9 (0.7, 1.2)	0.9 (0.7, 1.2)
60,000 - 100,000	568 (18.7)	81 (15.4)	14.2 (10.6, 17.8)	14.5 (11.1, 18.8)	Ref	Ref
Above 100,000	460 (15.1)	69 (13.0)	14.9 (10.4, 19.5)	14.4 (10.4, 19.6)	1.0 (0.8, 1.4)	1.0 (0.7, 1.3)
Prefer not to answer	443 (15.6)	51 (9.7)	11.5 (7.0, 16.0)	15.3 (9.5, 23.9)	0.8 (0.6, 1.1)	0.8 (0.6, 1.1)
DK	69 (2.3)	15 (2.8)	21.7 (6.1, 37.3)	27.6 (15.4, 44.4)	1.5 (0.9, 2.5)	1.4 (0.8, 2.2)
Employed						
Yes	1472 (48.4)	335 (63.5)	22.7 (18.6, 26.8)	19.9 (17.2, 22.9)	Ref	Ref
No/DK	1570 (51.6)	193 (36.6)	12.3 (9.6, 14.9)	12.9 (9.4, 17.3)	0.5 (0.5, 0.6)	0.6 (0.5, 0.7)
Geographic region						
Northeast	541 (17.8)	112 (21.3)	20.7 (15.1, 26.3)	19.7 (15.8, 24.3)	Ref	Ref
South	1153 (37.9)	181 (34.3)	15.7 (12.2, 19.2)	15.8 (12.7, 19.4)	0.8 (0.6, 0.9)	0.8 (0.6, 0.9)
Midwest	630 (20.7)	75 (14.2)	11.9 (7.6, 16.1)	11.8 (7.8, 17.4)	0.6 (0.4, 0.8)	0.6 (0.5, 0.8)
West	718 (23.6)	160 (30.3)	22.2 (15.7, 28.7)	21.9 (17.4, 27.0)	1.1 (0.9, 1.4)	1.1 (0.9, 1.4)
Vaccination status						
Fully vaccinated and boosted		374 (70.9)	23.2 (19.4, 27.0)	24.1 (20.9, 27.6)	3.5 (2.4, 4.7)	3.0 (2.1, 4.2)

Table 1 (*continued*)

	Total	SARS-CoV-2 cases	Crude prevalence of SARS-CoV-2 infection‡	Age and sex direct-standardized prevalence of SARS-CoV-2 infection**	Crude prevalence ratio (PR)	Adjusted prevalence ratio (aPR)***
	1610 (52.9)					
Fully vaccinated not boosted	476 (15.6)	33 (6.2)	6.9 (4.0, 9.8)	6.4 (4.2, 9.7)	Ref	Ref
Not vaccinated	957 (31.5)	121 (22.9)	12.6 (8.6, 16.9)	11.9 (8.7, 15.9)	1.8 (1.3, 2.6)	1.5 (1.1, 2.2)
Prior COVID since March 2020						
Never	1554 (51.1)	116 (21.9)	7.4 (5.7, 9.2)	7.6 (5.8, 10.0)	0.2 (0.2, 0.3)	0.2 (0.2, 0.3)
Once	808 (26.6)	272 (51.6)	33.6 (26.9, 40.2)	26.7 (22.6, 31.3)	Ref	Ref
More than once	343 (11.3)	89 (16.9)	25.9 (19.7, 31.1)	28.0 (22.5, 34.3)	0.8 (0.6, 0.9)	0.8 (0.7, 1.0)
Never tested positive but think they had COVID	335 (11.0)	51 (9.6)	15.1 (9.5, 20.7)	16.1 (10.9, 23.1)	0.5 (0.3, 0.6)	0.5 (0.4, 0.7)
SARS-CoV-2 immunity						
Vaccine- and infection-induced (hybrid)	987 (32.4)	315 (59.7)	31.9 (26.6, 37.2)	29.2 (25.3, 33.3)	Ref	Ref
Vaccine-induced only	1099 (36.1)	92 (17.4)	8.3 (6.2, 10.5)	8.3 (6.0, 11.6)	0.3 (0.2, 0.3)	0.3 (0.3, 0.4)
Infection-induced only	501 (16.5)	97 (18.3)	19.3 (12.5, 26.0)	17.0 (12.4, 22.8)	0.6 (0.5, 0.7)	0.6 (0.5, 0.8)
No prior SARS-CoV-2 immunity	456 (15.0)	24 (4.6)	5.3 (2.3, 8.2)	5.8 (3.2, 10.2)	0.2 (0.1, 0.2)	0.2 (0.1, 0.3)
Comorbidities						
Yes	1104 (36.3)	316 (59.9)	28.6 (23.5, 33.6)	28.8 (24.8, 33.2)	2.6 (2.2, 3.1)	2.8 (2.4, 3.3)
No	1938 (63.7)	212 (40.2)	10.9 (8.7, 13.1)	11.4 (9.3, 13.9)	Ref	Ref
Any vulnerability*						
Yes	2106 (69.2)	401 (76.1)	19.0 (15.9, 22.2)	19.6 (16.9, 22.5)	1.4 (1.2, 1.7)	1.6 (1.4, 2.0)
No	936 (30.8)	126 (23.9)	13.5 (10.1, 16.9)	12.6 (9.9, 16.1)	Ref	Ref
Health insurance						
Yes	2398 (78.8)	438 (83.0)	18.3 (15.4, 21.1)	19.1 (16.7, 21.7)	Ref	Ref
No	644 (21.2)	89 (17.0)	13.9 (9.5, 18.3)	12.9 (9.2, 17.9)	0.8 (0.6, 0.9)	0.6 (0.5, 0.8)

* Aged 65 or older OR > 1 comorbidity OR unvaccinated.
** Direct standardized for the age and sex groupings based in the 2020 U.S. census, except for age (standardized for sex only) and gender (standardized for age only).
*** Models adjusted for gender and age.

Similar to prior findings using the same methodology,(Qasmieh et al., 2022c; Qasmieh et al., 2022a) we estimated a higher prevalence of SARS-CoV-2 infection among those who were vaccinated and boosted compared with those who were fully vaccinated but not boosted and those who were unvaccinated. Since vaccines and boosters provide limited protection against infection with omicron variants compared with prior strains(Abu-Raddad et al., 2022) and due to the variable time since vaccination, differences in infection are likely due to differences in SARS-CoV-2 exposures and health behaviors between the two groups. Differences could also be partly explained by the higher testing rate among vaccinated and boosted persons, which when done for screening purposes, could result in greater detection of asymptomatic infection. These findings have important implications for observational (test negative) vaccine effectiveness (VE) studies, which are confounded by differences in exposure/behavior, testing behavior, and prior COVID between those vaccinated/boosted and unvaccinated.

We estimated 32.4% of adults had 'hybrid immunity' at the time of our survey. When we assessed the impact of both vaccination status and prior SARS-CoV-2 infection on risk of infection, we found that those with hybrid immunity had higher SARS-CoV-2 prevalence (29.2%), compared to those who had infection-induced immunity (17.0%), those who had vaccine-induced protection only (8.3%), and those who were SARS-CoV-2 naïve (5.8%). These findings suggest that prior infection, more so than vaccinations, may be an important marker for exposure risk during surges (e.g., workplace, household) and may also reflect a lower perceived risk for infection/reinfection. While there is evidence showing that prior infection may be negatively associated with decision to get the SARS-CoV-2 vaccine,(Kaim and Saban, 2022) the possible role of past and more recent SARS-CoV-2 infections (including their timing) in reducing the adoption of personal risk mitigation measures during surges needs to be further examined.

Ascertaining the various demographic and socio-economic characteristics that underpin the current risk profile of SARS-CoV-2 exposure and infection remains important. As of February 2022, anti-nucleocapsid (anti-N) seroprevalence estimates suggest that more than half the U.S. population has had a prior SARS-CoV-2 infection.(Clarke et al., 2022) Although SARS-CoV-2 primary vaccine and booster vaccination rates have stagnated,(Ritchie et al., n.d.) based on a nationwide survey of blood donors, approximately 95% of the U.S. population has some type of immunity (i.e., due to prior infection, vaccinations, or both).(CDC, 2020) With the continued circulation of SARS-CoV-2 sub-variants across the country, recently acquired hybrid immunity is likely to play an increasingly important role in determining the potential impact of future surges on severe outcomes.

We also found that among those who had tested, a substantial proportion had tested exclusively with at-home rapid antigen tests (30%) which are not captured via case-based passive surveillance. Exclusive at-home testing was highest among non-Hispanic White adults, those with college and above levels of education, and those who have household income above $60,000. It was lowest among non-Hispanic Blacks and

Table 2
SARS-CoV-2 diagnostic testing behaviors among U.S. adults across key characteristics, June 16 - July 2, 2022.

	Total	Non-testers	Testers (any)	Test with provider only	Test at home only	Test with both provider and at home	p-value**
	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)	
Total	3042 (100)	1758 (57.8)	1284 (42.2)	66 (2.2)	389 (12.3)	829 (27.3)	
Age							
18–24	365 (12.0)	132 (7.5)	233 (18.1)	15 (22.6)	27 (6.9)	191 (23.1)	
25–34	547 (18.0)	292 (16.6)	255 (19.8)	5 (7.7)	72 (18.5)	178 (21.5)	
35–44	495 (16.3)	329 (18.7)	166 (12.9)	14 (21.0)	46 (11.7)	107 (21.5)	
45–54	498 (16.4)	276 (15.7)	222 (17.3)	15 (22.1)	92 (23.7)	115 (13.9)	
55–64	508 (16.7)	325 (18.5)	182 (14.2)	4 (6.2)	75 (19.3)	103 (12.5)	
65+	629 (20.7)	403 (22.9)	226 (17.6)	13 (20.4)	78 (20.0)	135 (16.3)	<0.0001
Gender							
Male	1443 (47.5)	787 (44.7)	657 (51.2)	42 (64.1)	184 (47.3)	431 (52.0)	
Female	1516 (50.0)	946 (53.8)	570 (44.4)	23 (34.9)	197 (50.7)	350 (42.3)	
Non-binary	82 (2.7)	26 (1.5)	57 (4.4)	1 (1.0)	8 (2.1)	48 (5.8)	<0.0001
Race/ethnicity							
Black NH	350 (11.5)	196 (11.2)	154 (12.0)	10 (14.8)	38 (9.9)	394 (47.6)	
White NH	1794 (59.0)	1122 (63.8)	671 (52.3)	23 (34.4)	254 (65.3)	106 (12.8)	
Hispanic	460 (15.1)	176 (10.0)	284 (22.1)	21 (32.1)	47 (12.1)	216 (26.0)	
Asian/Pacific islander	171 (5.6)	82 (4.7)	88 (6.9)	4 (6.6)	24 (6.2)	60 (7.2)	
Other	268 (8.8)	182 (10.3)	86 (6.7)	8 (12.2)	25 (6.5)	53 (6.4)	<0.0001
Years of education							
Some HS and below	353 (11.6)	101 (5.7)	252 (19.7)	12 (18.6)	23 (5.8)	218 (26.2)	
HS grad	830 (27.3)	501 (28.5)	330 (25.7)	27 (41.0)	92 (23.7)	211 (25.4)	
Some college	934 (30.7)	594 (33.8)	340 (26.5)	11 (17.2)	123 (31.5)	206 (24.9)	
College grad and above	925 (30.4)	563 (32.1)	361 (28.2)	15 (23.2)	152 (39.0)	195 (23.5)	<0.0001
Household income							
Below 20 K	561 (18.4)	253 (14.4)	308 (24.0)	18 (27.1)	45 (11.5)	245 (29.6)	
20,000 - 60,000	941 (31.0)	570 (32.4)	371 (28.9)	20 (29.7)	107 (27.6)	244 (29.5)	
60,000 - 100,000	568 (18.7)	332 (18.9)	236 (18.4)	13 (19.3)	101 (25.9)	123 (14.8)	
Above 100,000	460 (15.1)	283 (16.1)	177 (13.8)	4 (5.5)	80 (20.6)	93 (11.2)	
Prefer not to answer	443 (15.6)	274 (15.6)	169 (13.2)	8 (12.7)	55 (14.3)	105 (12.7)	
DK	69 (2.3)	46 (2.6)	23 (1.8)	4 (5.8)	1 (0.2)	19 (2.3)	<0.0001
Employed							
Yes	1472 (48.4)	798 (45.4)	674 (52.5)	32 (48.5)	206 (52.9)	437 (53.7)	
No/DK	1570 (51.6)	961 (54.6)	610 (47.5)	34 (51.5)	183 (47.1)	392 (47.3)	<0.0001
Geographic region							
Northeast	541 (17.8)	271 (15.4)	270 (21.0)	11 (16.9)	69 (17.7)	190 (22.9)	
South	1153 (37.9)	709 (40.3)	444 (34.6)	28 (42.7)	142 (36.4)	275 (33.1)	
Midwest	630 (20.7)	386 (22.0)	243 (19.0)	9 (13.8)	80 (20.5)	154 (18.6)	
West	718 (23.6)	392 (22.3)	326 (25.4)	17 (26.6)	99 (25.4)	210 (25.3)	<0.0001
Vaccination status							
Fully vaccinated and boosted	1610 (52.9)	809 (46.0)	800 (62.3)	24 (37.1)	253 (65.1)	522 (63.0)	
Fully vaccinated not boosted	476 (15.6)	329 (18.7)	147 (11.4)	15 (23.4)	59 (15.3)	72 (8.7)	
Not vaccinated	957 (31.5)	620 (35.3)	337 (26.3)	26 (40.0)	76 (19.6)	235 (28.3)	<0.0001
Prior COVID since March 2020							
Never	1554 (51.1)	1112 (63.2)	442 (34.5)	33 (49.7)	199 (51.2)	211 (25.4)	
Once	808 (26.6)	359 (20.4)	451 (35.1)	24 (37.0)	117 (30.0)	310 (37.4)	<0.0001
More than once	343 (11.3)	69 (3.9)	274 (21.4)	2 (2.4)	24 (6.1)	249 (30.0)	
Never tested positive but think they had COVID	335 (11.0)	218 (12.4)	116 (9.1)	7 (10.9)	50 (12.8)	60 (7.2)	
SARS-CoV-2 immunity							
Vaccine- and infection-induced (hybrid)	987 (32.4)	402 (22.9)	585 (45.6)	15 (22.4)	145 (37.2)	425 (51.3)	
Vaccine-induced only	1099 (36.1)	737 (41.9)	362 (28.2)	25 (38.1)	168 (43.2)	169 (20.4)	<0.0001
Infection-induced only	501 (16.5)	245 (13.9)	256 (20.0)	18 (27.9)	45 (11.6)	193 (23.3)	
No prior SARS-CoV-2 immunity	456 (15.0)	375 (21.3)	81 (6.3)	8 (11.7)	31.1 (8.0)	42 (5.1)	
Comorbidities							
Yes	1104 (36.3)	584 (33.2)	520 (40.5)	20 (30.0)	134 (34.6)	366 (44.1)	<0.0001
No	1938 (63.7)	1174 (66.8)	764 (59.5)	46 (70.0)	255 (65.4)	463 (55.9)	
Any vulnerability*							0.04
Yes	2106 (69.2)	1243 (70.7)	863 (67.3)	47 (71.4)	232 (59.6)	584 (70.5)	

(continued on next page)

Table 2 (*continued*)

	Total	Non-testers	Testers (any)	Test with provider only	Test at home only	Test with both provider and at home	
No Health insurance	936 (30.8)	515 (29.3)	420 (32.8)	19 (28.6)	157 (40.4)	245 (29.5)	
Yes	2398 (78.8)	1367 (77.8)	1031 (80.3)	53 (79.8)	336 (86.3)	643 (77.6)	0.09
No	644 (21.2)	391 (22.2)	253 (19.7)	13 (20.3)	53 (13.7)	186 (22.5)	

[*] Aged 65 or older OR > 1 comorbidity OR unvaccinated.

[**] Compares those who test at all with those who do not test at all.

Table 3

Prevalence of long COVID among U.S. adults across key characteristics, June 16 - July 2, 2022[*, **]

	Had COVID more than one month ago	Long COVID	Crude prevalence of long COVID	Age and sex direct-standardized prevalence of long COVID[*]	Crude prevalence ratio (PR)	Adjusted prevalence ratio (aPR)[**]
	N (%)	N (%)	% (95% CI)	% (95% CI)	PR (95% CI)	aPR (95% CI)
Total	1036 (100.0)	222 (100.0)	21.5 (18.2, 24.7)			
Age						
18–24	70 (6.8)	17 (7.8)	24.8 (7.5, 42.0)	18.6 (8.8, 35.2)	1.1 (0.7, 1.7)	1.2 (0.7, 1.9)
25–34	250 (24.2)	58 (26.1)	23.2 (15.2, 31.2)	22.3 (15.2, 31.5)	Ref	Ref
35–44	178 (17.2)	43 (19.1)	23.9 (15.5, 32.3)	27.6 (19.3, 37.8)	1.0 (0.7, 1.5)	1.2 (0.9, 1.8)
45–54	171 (16.5)	37 (16.5)	21.6 (13.9, 29.3)	22.3 (15.6, 30.9)	0.9 (0.7, 1.3)	1.1 (0.7, 1.5)
55–64	185 (17.9)	41 (18.2)	21.9 (15.5, 28.3)	23.1 (17.2, 30.3)	0.9 (0.7, 1.4)	1.1 (0.8, 1.5)
65+	182 (17.6)	27 (12.2)	14.9 (10.5, 19.2)	14.8 (10.8, 19.9)	0.6 (0.4, 1.0)	0.7 (0.5, 1.1)
Gender						
Male	465 (44.9)	72 (32.4)	15.5 (11.6, 19.4)	15.5 (11.9, 20.2)	Ref	Ref
Female	528 (51.0)	144 (64.8)	27.3 (22.2, 32.4)	27.4 (22.8, 32.6)	1.8 (1.4, 2.3)	1.8 (1.4, 2.3)
Non-binary	43 (4.2)	6 (2.8)	14.2 (0.0, 31.8)	13.3 (4.8, 32.1)	0.9 (0.4, 1.9)	0.9 (0.4, 1.9)
Race/ethnicity						
Black NH	75 (7.2)	19 (8.4)	24.9 (11.8, 38.1)	27.3 (17.0, 41.0)	1.2 (0.8, 1.8)	1.1 (0.7, 1.7)
White NH	690 (66.6)	148 (66.8)	21.5 (18.0, 25.1)	22.4 (18.9, 26.5)	Ref	Ref
Hispanic	129 (12.5)	22 (9.7)	16.8 (5.4, 28.1)	16.8 (9.0, 29.2)	0.8 (0.5, 1.2)	0.8 (0.6, 1.2)
Asian/Pacific islander	41 (4.0)	7 (3.2)	17.6 (0.0, 37.5)	11.0 (3.4, 30.6)	0.82 (0.4, 1.6)	0.8 (0.4, 1.7)
Other	101 (9.8)	26 (11.8)	26.0 (13.1, 38.9)	29.0 (19.7, 40.6)	1.2 (0.8, 1.7)	1.4 (0.9, 1.9)
Years of education						
Some HS and below	68 (6.5)	16 (7.1)	23.3 (4.8, 41.7)	18.1 (7.4, 38.0)	1.3 (0.8, 2.1)	1.2 (0.7, 1.9)
HS grad	289 (27.9)	69 (31.0)	23.9 (16.7, 31.0)	22.7 (15.8, 31.5)	1.3 (1.0, 1.8)	1.2 (0.9, 1.6)
Some college	331 (31.9)	75 (33.9)	22.8 (17.1, 28.6)	23.1 (18.0, 29.1)	1.3 (1.0, 1.7)	1.2 (0.9, 1.6)
College grad and above	349 (33.7)	62 (28.0)	17.8 (13.8, 21.9)	19.8 (15.7, 24.6)	Ref	Ref
Household income						
Below 20 K	134 (12.9)	34 (15.4)	25.6 (14.8, 36.4)	17.9 (11.5, 26.9)	1.6 (1.0, 2.4)	1.5 (0.9, 2.3)
20,001 - 60,000	332 (32.0)	83 (37.2)	24.9 (18.6, 31.2)	25.0 (19.1, 31.9)	1.5 (1.1, 2.2)	1.5 (1.0, 2.1)
60,001 - 100,000	213 (20.6)	48 (21.8)	22.7 (15.9, 29.5)	23.2 (17.1, 30.5)	1.4 (0.9, 2.1)	1.3 (0.9, 2.0)
Above 100,000	197 (19.0)	32 (14.4)	16.3 (10.2, 22.4)	20.9 (14.5, 29.2)	Ref	Ref
Prefer not to answer	160 (15.4)	25 (11.1)	15.5 (8.2, 22.7)	15.6 (9.0, 25.8)	1.0 (0.6, 1.5)	1.0 (0.6, 1.7)
Employed						
Yes	548 (52.9)	123 (55.3)	22.4 (17.8, 27.1)	24.3 (20.0, 29.3)	1.1 (0.9, 1.4)	1.1 (0.9, 1.4)
No/DK	488 (47.1)	99 (44.7)	20.4 (15.8, 25.0)	27.5 (20.6, 35.7)	Ref	Ref
Geographic region						
Northeast	187 (18.0)	29 (13.2)	15.8 (10.1, 21.4)	17.2 (11.8, 24.3)	Ref	Ref
South	402 (38.8)	92 (41.5)	23.0 (17.8, 28.2)	22.6 (18.1, 27.9)	1.5 (1.0, 2.1)	1.5 (1.0, 2.1)
Midwest	245 (23.6)	52 (23.6)	21.4 (14.9, 28.0)	20.3 (14.7, 27.3)	1.4 (0.9, 2.1)	1.4 (1.0, 2.2)
West	203 (19.6)	48 (21.6)	23.7 (14.7, 32.7)	21.7 (14.9, 30.5)	1.5 (1.0, 2.3)	1.5 (1.0, 2.3)
Vaccination status						
Fully vaccination and boosted	448 (43.3)	86 (38.7)	19.2 (14.8, 23.5)	20.9 (16.4, 26.2)	Ref	Ref
Fully vaccinated not boosted	196 (18.9)	49 (22.2)	25.1 (16.9, 33.4)	24.9 (18.2, 33.0)	1.3 (1.0, 1.8)	1.2 (0.9, 1.6)
Not vaccinated	392 (37.8)	87 (39.2)	22.2 (16.6, 27.9)	22.8 (17.5, 29.1)	1.2 (0.9, 1.5)	1.1 (0.8, 1.4)
Comorbidities						
Yes	315 (30.4)	96 (43.3)	30.6 (24.5, 36.8)	32.8 (25.9, 40.5)	1.8 (1.4, 2.2)	1.8 (1.4, 2.3)
No	721 (69.6)	126 (56.7)	17.5 (13.7, 21.2)	17.5 (14.2, 21.4)	Ref	Ref
Health insurance						
Yes	809 (78.1)	190 (85.7)	23.5 (19.8, 27.3)	23.6 (20.1, 27.6)	1.7 (1.2, 2.4)	1.9 (1.3, 2.7)
No	227 (21.9)	32 (14.3)	14.0 (7.7, 20.3)	14.1 (0.9, 22.1)	Ref	Ref

[*] Direct standardized for the age and sex groupings based in the 2020 U.S. census, except for age (standardized for sex only) and gender (standardized for age only).

[**] Models adjusted for gender and age.

those with below high-school education. These findings are consistent with another study on the uptake of at-home test use.(Rader et al., 2022) We also found that 39.6% of our respondents have tested with at-home rapid tests, which is higher than a previous estimate of 20% of adults who tested with an at-home test during the BA.1 surge period.(Clarke et al., 2022; Ritchie et al., n.d.) The differential use of at-home tests by demographic characteristics and the increase in use of at-home testing over time provides insights about the groups in which infections are likely being undercounted by routine case-based surveillance.

Among respondents with SARS-CoV-2 infection more than four weeks ago, an estimated 21.5% reported currently having long COVID symptoms. Consistent with our estimates, the U.S. Household Pulse Survey (HPS), an online survey sampling households which began collecting information on long COVID in June 2022, estimated 18.9% (95% CI 17.9, 19.8) of U.S. adults were currently experiencing long COVID. (Long COVID, n.d.) Our study, which was not restricted to persons accessing medical care, observed a lower prevalence of long COVID among the oldest (65+ years) versus younger age groups than reported elsewhere in the literature.(Thompson et al., 2022; Subramanian et al., 2022) This may be due to an overrepresentation of hospitalized or care-seeking patients in long COVID studies versus non-hospitalized populations. It could also reflect SARS-CoV-2 infection mitigation behaviors, such as mask wearing of social distancing, as well as higher early uptake of vaccines and boosters in older U.S. residents, or survival bias (i.e., younger people are more likely to survive COVID-19 enabling them to report long symptoms of prior infection). Due to limited space in our survey questionnaire, we could not ascertain SARS-CoV-2 immunity status at the time of prior infection, and therefore could not stratify long COVID prevalence across SARS-CoV-2 immunity categories.

Our study has some limitations worth noting. First, our survey may have overestimated SARS-CoV-2 prevalence and provider testing if those with SARS-CoV-2 infection were more likely to participate in the survey. While potential survey participants were not aware of the survey content before deciding to participate, it may be that those who were positive were more likely to complete the survey. It is also possible that participants inadvertently recalled and reported positive tests that were beyond the 14-day study period (recall bias). In addition, some people test multiple times over a period of days or weeks with providers after their initial positive test,(Rane et al., 2022) and subsequently, many can expect positive PCR and antigen test results for 10 or more days.(Boucau et al., 2022; Lefferts et al., 2022) This could have caused some people who were diagnosed prior to the study period to have positive tests during the study period which could have inflated our prevalence estimates relative to official case counts.

Since not all respondents tested in the two weeks prior to the survey, and since we could not collect biomarker data, our case definition based on symptoms and epidemiologic linkage would likely capture a subset of the estimated 20–30% of individuals whose SARS-CoV-2 infection may remain asymptomatic throughout their infection who also happened to test during their asymptomatic infection (e.g., due to routine screening or because of a known exposure)(Ma et al., 2021) as well as those who were symptomatic but were not aware of a close contact. To avoid confusion with acute COVID symptoms, we did not assess long COVID among respondents whose most recent SARS-CoV-2 infection was within the past month. However, some of these individuals may have long COVID from an earlier SARS-CoV-2 infection, which would result in an underestimation of the prevalence of long COVID. Finally, our survey did not include children or those whose primary language was not English or Spanish.

Strengths of our study include the representative and probability-based design of the survey, and the ability for the survey to reflect outcomes among those who do not access the healthcare system for SARS-CoV-2 and long COVID. Other strengths include the measurement of several important factors that are not currently available through routine surveillance, including outcomes among individuals vulnerable to COVID-19, hybrid immunity, and long COVID.

5. Conclusions

We estimated a prevalence of SARS-CoV-2 during the BA.4/BA.5 surge among adults in the U.S indicating substantial levels of SARS-CoV-2 circulation, much higher than official CDC case counts would suggest, with substantial disparities along the lines of social determinants of health. We also find that a significant proportion of U.S. adults with prior COVID (1 in five) report experiencing prolonged symptoms of long COVID which aligns with estimates from a previous CDC publication. (Long COVID, n.d.) Our findings demonstrate the utility of population-representative surveys as an important surveillance tool to go alongside, and triangulate, with passive case reporting at an evolving stage of the U.S. pandemic.

Data availability

Data will be made available on request.

Appendix 1 (Survey design)

Sampling Frame. A sampling frame of 254,297,978 Residents of the United States consisting of 105,469,157 mobile numbers with an additional 60,126,857 landlines. Two stratified proportionate randomized population-based samples were drawn for this study, $n = 90,000$ mobile numbers and $n = 50,000$ landlines. A National opt-in Online Panel provided by Consensus Strategies was used in the study. A total sample of $n = 3,042$ was utilized with a +/- 3% margin of error. Data was collected June 30 - July 2, 2022.

Multi-mode data collection design. Short message service (SMS) aka text messages were sent using SMS platform. The respondents were sent a personalized first name text message which included a link to the survey and an opt-out option. The respondents had the option to reply to the SMS text with any queries. Data was verified by IP address and scrubbed against the original survey sample.

Interactive voice response (IVR) aka robo-poll messages were sent to landlines. The respondents were able to answer the survey questions using the touch tone keypad on their phones.

The opt-in online panel was created by Consensus Strategies and participants were paid an incentive to complete the surveys of up to $2. Respondents were verified by payment information.

Survey weighting. The survey was weighted using an iterative weighting method (raking) to marginal proportions of race, ethnicity, age, self-identified sex, and education by U.S. region. The samples (landline, online, mobile) were normalized at the region level based on sex, age, gender,

education, race, and sample size then combined and weighted back based on the proportion of the region to the overall population and the other demographics. The sum of the weights equals the sample population ($n = 3,042$). Demographic weights were created based on the American Community Survey 5-year estimates and 2020 US Census. The inference population is 254,297,978 million adults in the U.S.

Response rates. Our overall combined response rates across all modalities were 7.2%. The response rate was 6.2% for random digit dial to landline, 0.9% for cell phone, and 86.5% for opt-in online panel. The response rate reflects the proportion of complete respondents among eligible participants in the sampling frame. For context, we also included response rates for the Household Pulse Survey (HPS) in 2020 and 2022. While our response rates are comparable, the HPS methodology calculates the response rate based on completes and sufficient partial interviews, compared to our rates which are based on complete interviews (i.e., more conservative rates).

Mode	National COVID-19 Survey (June–July 2022)				HPS 2022 Jun 29-Jul 11	HPS 2022 Jun 1-Jun 13	HPS 2020 Week 1	HPS 2020 Week 2	HPS 2020 Week 3
	Landline	Cell	Online opt-in panel	Combined					
RR	6.2	0.9	86.5	7.2	5.7	6.2	3.8	1.3	2.3

Appendix 2 (Survey questionnaire)

Survey on recent COVID exposure, COVID infection, and testing behaviors in the United States.

Hello, this is [interviewer] with a brief public policy survey. At no time will we try to sell you anything. We are just interested in your opinions, and you can drop out at any time.

To begin, what language would you like to take this survey in?

1. English
2. Español

The following questions will ask about COVID exposure in the past 2 weeks.

1. In the past 2 weeks, have you experienced any COVID-like symptoms (e.g., 100 degrees fever or higher, chills, cough, sore throat, fatigue, headache, shortness of breath, congestion or runny nose, muscle aches, loss of smell or taste, nausea, or diarrhea)?

a. Yes

  b. No.
  c. Don't know/not sure.

2. In the past 2 weeks, were you aware of an exposure you had to someone who had COVID-like symptoms or tested positive for COVID-19?

a. Yes
b. No
c. Don't know/not sure

The following questions will ask about COVID testing in the past 2 weeks.

3. In the past 2 weeks, have you taken an at-home rapid test for COVID-19? (a rapid at-home test allows you to collect your own sample and get results within minutes at home)

a. Yes, Tested Positive
b. Yes, Tested Negative
c. No, I have not tested

4. In the past 2 weeks, have you taken a rapid antigen or PCR test for COVID-19 from a healthcare or testing provider?

a. Yes, Tested Positive
b. Yes, Tested Negative
c. No, I have not tested [skip to 6]

5. *If tested with a healthcare provider.* When you tested with a healthcare or testing provider, which type of test did you receive?

a. Rapid test/point of care test
b. PCR test
c. Both
d. Not sure/don't know

6. Prior to June 15th, 2022, did you ever have COVID-19 infection, either diagnosed by a healthcare or testing provider, or based on a positive at-home rapid test?

a. Yes, once
b. Yes, more than once
c. No, but I am pretty sure that I had COVID
d. No, I don't think I have ever had COVID [skip to 8]
e. Don't know/not sure [skip to 8]

7. When was the last time you had COVID?

a. Within the last month (if you currently have COVID, choose this option)
b. 1–3 months ago
c. 3–6 months ago
d. 6–12 months ago
e. >12 months ago
f. Don't know/not sure

Long COVID.

8. Would you describe yourself as having 'long COVID', that is you experienced symptoms such as fatigue, difficulty concentrating, shortness of breath more than 4 weeks after you first had COVID-19 that are not explained by something else?

a. Yes
b. No [skip to 10]
c. Don't know/not sure [skip to 10]

9. Does this reduce your ability to carry-out day-to-day activities compared with the time before you had COVID-19?

a. Yes, a lot
b. Yes, a little
c. Not at all
d. Don't know/not sure

Respondent Characteristics.

10. Do you currently have any kind of health care coverage, including health insurance, prepaid plans such as HMOs, or government plans such as Medicaid or Medicare, or Indian Health Service?

a. Yes
b. No
c. Don't know/not sure

11. Do you have any of the following conditions that could increase the severity of COVID-19: cancer, diabetes, obesity, COPD or lung disease, liver disease, heart disease, high blood pressure, a recent organ transplant, or an immunodeficiency)?

a. Yes
b. No
c. Don't know/not sure

12. Have you been fully vaccinated against COVID-19? [Either 2 doses of mRNA vaccine series (Moderna or Pfizer) or a single dose of Johnson and Johnson COVID-19 vaccine]

a. Yes
b. No (go to 14)
c. Don't know/not sure (go to 14)

13. If you have been fully vaccinated, have you also received at least one coronavirus booster?

a. Yes, >5 months ago
b. Yes, within the past 5 months
c. No

14. If not fully vaccinated OR not boosted: Do you plan to get a vaccine dose or booster in the next two weeks?

a. Yes

b. No
c. Don't know/not sure

15. What is your age?

a. 18–24
b. 25–34
c. 35–44
d. 45–49
e. 50–54
f. 55–64
g. 65–74
h. 75 +

16. How do you currently identify your gender? Do you identify as …

a. Male
b. Female
c. Gender non-binary
d. other

17. Which one of the following would you use to describe yourself?

a. Latino/a, or of Hispanic or Spanish origin
b. White
c. Black or African American
d. Asian, Native Hawaiian or Other Pacific Islander
e. American Indian/Alaska Native
f. More than one race
g. Other

18. What is the highest grade or year of school you completed?

a. Less than high school
b. Grade 12 or GED (High school graduate)
c. College 1 year to 3 years (Some college or technical school, associate degree)
d. College 4 years or more (College graduate)

19. Are you currently employed for wages or salary?

a. Yes
b. No
c. Don't know/not sure

20. What is your household's annual income?
    a. $20,000 or less
    b. Between $20,001 - $40,000
    c. Between $40,001 - $60,000
    d. Between $60,001 - $80,000
    e. Between $80,001 - $100,000
    f. Above $100,000
    g. Prefer not to answer
    h. Don't know/not sure

References

Abu-Raddad, L.J., Chemaitelly, H., Ayoub, H.H., et al., 2022. Effect of mRNA vaccine boosters against SARS-CoV-2 omicron infection in Qatar. N. Engl. J. Med. 386 (19), 1804–1816.

Boucau, J., Marino, C., Regan, J., et al., 2022. Duration of shedding of culturable virus in SARS-CoV-2 omicron (BA.1) infection. N. Engl. J. Med. https://doi.org/10.1056/NEJMc2202092. Published online June 29.

Bull-Otterson, L., Baca, S., Saydah, S., et al., 2022. Post–COVID conditions among adult COVID-19 survivors aged 18–64 and ≥65 years — United States, march 2020–November 2021. MMWR Surveill. Summ. 71 (21), 713.

CDC, 2020. COVID data tracker. In: Antibody Seroprevalence. Centers for Disease Control and Prevention. Published March 28. Accessed August 27, 2022. https://covid.cdc.gov/covid-data-tracker/#trends_dailycases_select_00.

CDC, 2020a. COVID data tracker. In: Variants & Genomic Surveillance. Centers for Disease Control and Prevention. Published March 28, 2020. Accessed July 19, 2022. https://covid.cdc.gov/covid-data-tracker/#variant-proportions.

CDC, 2020b. COVID data tracker. Cases, Deaths, & Testing. Centers for Disease Control and Prevention. Published March 28, 2020. Accessed August 27, 2022. https://covid.cdc.gov/covid-data-tracker/#trends_dailycases_select_00.

Clarke, K.E.N., Jones, J.M., Deng, Y., et al., 2022. Seroprevalence of infection-induced SARS-CoV-2 antibodies — United States, September 2021–February 2022. MMWR

Morb. Mortal. Wkly Rep. 71 (17), 606–608. https://doi.org/10.15585/mmwr.mm7117e3.

Coronavirus (COVID-19) Infection Survey: methods and further information. Accessed August 23, 2022. https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/methodologies/covid19infectionsurveypilotmethodsandfurtherinformation.

CSTE Interim Position Statement: Update to COVID-19 Case Definition - Council of State and Territorial Epidemiologists. Accessed April 23, 2022. https://www.cste.org/news/520707/CSTE-Interim-Position-Statement-Update-to-COVID-19-Case-Definition.htm.

Dean, N., 2022. Tracking COVID-19 infections: time for change. Nature. 602 (7896), 185.

Gold, J.A.W., DeCuir, J., Coyle, J.P., et al., 2021. COVID-19 case surveillance: trends in person-level case data completeness, United States, April 5–September 30, 2020. Public Health Rep. 136 (4), 466–474.

Jones, J.M., Opsomer, J.D., Stone, M., et al., 2022. Updated US infection- and vaccine-induced SARS-CoV-2 seroprevalence estimates based on blood donations, July 2020-December 2021. JAMA. 328 (3), 298–301.

Kaim, A., Saban, M., 2022. Are we suffering from the Peltzman effect? Risk perception among recovered and vaccinated people during the COVID-19 pandemic in Israel. Public Health 209, 19–22.

Lefferts, B., Blake, I., Bruden, D., et al., 2022. Antigen test positivity after COVID-19 isolation - Yukon-Kuskokwim Delta region, Alaska, January-February 2022. MMWR Morb. Mortal. Wkly Rep. 71 (8), 293–298.

Link-Gelles, R., Levy, M.E., Gaglani, M., et al., 2022. Effectiveness of 2, 3, and 4 COVID-19 mRNA Vaccine Doses Among Immunocompetent Adults During Periods when SARS-CoV-2 Omicron BA.1 and BA.2/BA.2.12.1 Sublineages Predominated — VISION Network, 10 States, December 2021–June 2022. MMWR Morb. Mortal. Wkly Rep. 71 (29), 931–939. https://doi.org/10.15585/mmwr.mm7129e1.

Long COVID. Published July 19, 2022. Accessed August 12, 2022. https://www.cdc.gov/nchs/covid19/pulse/long-covid.htm.

Ma, Q., Liu, J., Liu, Q., et al., 2021. Global percentage of asymptomatic SARS-CoV-2 infections among the tested population and individuals with confirmed COVID-19 diagnosis: a systematic review and Meta-analysis. JAMA Netw. Open 4 (12), e2137257.

Nash, D., Geng, E., 2020. Goal-aligned, epidemic intelligence for the public health response to the COVID-19 pandemic. Am. J. Public Health 110 (8), 1154–1156.

Perlis, R.H., Santillana, M., Ognyanova, K., et al., 2022. Prevalence and correlates of Long COVID symptoms among US adults. JAMA Netw. Open 5 (10), e2238804.

Qasmieh, S.A., Robertson, M.M., Teasdale, C.A., Kulkarni, S.G., Nash, D., 2022a. Estimating the period prevalence of SARS-CoV-2 infection during the Omicron (BA.1) surge in New York City (NYC), January 1-March 16, 2022. Published online April 27. https://doi.org/10.1101/2022.04.23.22274214.

Qasmieh SA, Robertson MM, Teasdale CA, Kulkarni SG, Nash D. Estimating the period prevalence of SARS-CoV-2 infection during the Omicron (BA.1) surge in New York City (NYC), January 1-March 16, 2022. Clin. Infect. Dis.. Published online August 12, 2022b. doi:https://doi.org/10.1093/cid/ciac644.

Qasmieh, S.A., Robertson, M.M., Teasdale, C.A., et al., 2022c. The prevalence of SARS-CoV-2 infection and other public health outcomes during the BA.2/BA.2.12.1 surge, New York City, April–May 2022. bioRxiv. https://doi.org/10.1101/2022.05.25.22275603. Published online May 26, 2022.

Rader, B., Gertz, A., Iuliano, A.D., et al., 2022. Use of at-home COVID-19 tests - United States, august 23, 2021-march 12, 2022. MMWR Morb. Mortal. Wkly Rep. 71 (13), 489–494.

Rane, M.S., Profeta, A., Poehlein, E., et al., 2022. SARS-CoV-2 pandemic in New York metropolitan area: the view from a major urgent care provider. Ann. Epidemiol. https://doi.org/10.1016/j.annepidem.2022.05.006. Published online June 2.

Ritchie, Mathieu, Rodés-Guirao, et al. Coronavirus Pandemic (COVID-19). Our World in Data. https://ourworldindata.org/covid-vaccinations.

Robertson, M.M., Shamsunder, M.G., Brazier, E., et al., 2022. Racial/ethnic disparities in exposure, disease susceptibility, and clinical outcomes during COVID-19 pandemic in national cohort of adults, United States. Emerg. Infect. Dis. 28 (11), 2171–2180.

Sherratt, K., Abbott, S., Meakin, S.R., et al., 1829. Exploring surveillance data biases when estimating the reproduction number: with insights into subpopulation transmission of COVID-19 in England. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 2021 (376), 20200283.

Shircliff, E.J., Rosenberg, E.S., Collens, L.M., et al.. Notes from the Field School-Based and Laboratory-Based Reporting of Positive COVID-19 Test Results among School-Aged Children -New York, September 11, 2021-April 29, 2022. Accessed January 3, 2023.

Simpson, R.B., Lauren, B.N., Schipper, K.H., McCann, J.C., Tarnas, M.C., Naumova, E.N., 2022. Critical periods, critical time points and day-of-the-week effects in COVID-19 surveillance data: an example in Middlesex County, Massachusetts, USA. Int. J. Environ. Res. Public Health vol. 19 (3). https://doi.org/10.3390/ijerph19031321.

Subramanian, A., Nirantharakumar, K., Hughes, S., et al., 2022. Symptoms and risk factors for long COVID in non-hospitalized adults. Nat. Med. 28 (8), 1706–1714.

Thompson, E.J., Williams, D.M., Walker, A.J., et al., 2022. Long COVID burden and risk factors in 10 UK longitudinal studies and electronic health records. Nat. Commun. 13 (1), 3528.

United States Census Bureau. QuickFacts: United States. Accessed August 2, 2022. https://www.census.gov/quickfacts/fact/table/US/PST045221.

Walgreens COVID-19 index. Walgreens. Accessed August 24, 2022. https://www.walgreens.com/businesssolutions/covid-19-index.jsp.