



# Characteristics and Behaviors Associated with Prevalent SARS-CoV-2 Infection

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**Introduction:** Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes coronavirus disease 2019 (Covid-19), has been a serious threat to global health. Previous work has focused primarily on hospitalized patients or on identifying risk factors for disease severity and mortality once the infection has taken place. We sought to leverage the ubiquity of smartphones and mobile applications to study risk factors for Covid-19 infection in a large, geographically heterogeneous cohort.

**Methods:** We analyzed data obtained from the Covid-19 Citizen Science (CCS) Study, a worldwide, mobile application-based cohort. After employing forward selection to identify variables with  $p$  values  $< 0.1$ , multivariable logistic regression models were utilized to identify independent risk factors associated with prevalent SARS-CoV-2 infection.

**Results:** Among 36,041 participants in 113 countries and all 50 states in the US, 484 participants had prevalent SARS-CoV-2 infection. After multivariable adjustment, being a healthcare worker, living with at least one school-aged child, having pets at home, and having immunodeficiency were each associated with an increased odds of SARS-CoV-2. The association between pets and prevalent SARS-CoV-2 was driven by dog ownership. After adjustment for the same covariates, Asian or Pacific Islander race, receiving a flu shot within the past year, increased level of education, and smoking or vaping marijuana within the last 30 days were each associated with a lower odds of SARS-CoV-2.

**Conclusion:** We identified various characteristics and behaviors, many of which are potentially modifiable, associated with prevalent SARS-CoV-2 infection in a world-wide mobile application-based cohort.

**Keywords:** COVID-19, epidemiology, cohort study, digital health, mobile applications

## Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes coronavirus disease 2019 (Covid-19), has had a significant impact on communities across the globe. Identifying risk factors associated with Covid-19 may prove valuable to the delivery of targeted public health interventions, providing more personalized advice to high-risk patient populations, and better informing the global response to the pandemic. Participation among community members and organizations has played a key role during the Covid-19 pandemic,<sup>1</sup> and identifying potentially modifiable risk factors that can support community-based interventions is vital for containment of the pandemic.

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Previous work has focused on hospitalized patients<sup>2</sup> or on disease severity and mortality once infection has taken place.<sup>3</sup> Furthermore, smartphone technology on its own, and as an extension of telemedicine, has had various applications during the Covid-19 pandemic.<sup>4</sup> We therefore sought to leverage the ubiquity of smartphones and mobile applications to study risk factors for Covid-19 infection in a large, geographically heterogeneous cohort.

## Methods

We conducted a cross-sectional study using data obtained from the Covid-19 Citizen Science (CCS) Study, a worldwide, mobile application-based cohort (<https://covid19.eurekaplatform.org>). Surveys pertinent to the current analyses are included in the [Supplemental Materials](#). Questions where “effect-cause” relationships could obscure inferred causal relationships with prevalent disease were excluded.

Prevalent SARS-CoV-2 infection was defined as a history of a positive polymerase chain reaction (PCR) test for active infection. Participants were initially screened in the baseline survey for a history of any positive test for infection. Given an affirmative response to that initial question, participants were asked to distinguish between a PCR test for active infection versus an antibody test for prior infection. Self-report was verified by documentation of test results ([Supplemental Materials](#)). We identified variables exhibiting  $p$  values  $< 0.1$  for associations with prevalent disease after adjusting for age, sex, race/ethnicity and then employed forward selection in a multivariable logistic regression model, retaining variables with  $p$  values  $< 0.1$ . Statistical analyses were performed using Stata, version 16 (College Station, TX). Two-tailed  $p$ -values  $< 0.05$  were considered statistically significant. The study was approved by the University of California, San Francisco Institutional Review Board. All participants provided informed electronic consent.

## Results

Among 36,041 participants in 113 countries and all 50 states in the US, 484 participants had prevalent SARS-CoV-2 infection ([Supplemental Figure 1](#)) (4297 participants had a negative test, and 31,260 participants were not tested). Baseline participant characteristics are shown in [Table 1](#). After multivariable adjustment,

being a healthcare worker, living with at least one school-aged child, having pets at home, and having immunodeficiency were each associated with an increased odds of SARS-CoV-2 ([Figure 1](#)). The association between pets and prevalent SARS-CoV-2 was driven by dog ownership ([Supplemental Tables 1 and 2](#)). After multivariable adjustment for the same covariates, Asian or Pacific Islander race, receiving a flu shot within the past year, increased level of education, and smoking or vaping marijuana within the last 30 days were each associated with a lower odds of SARS-CoV-2 ([Figure 1](#)).

## Discussion

We identified characteristics associated with prevalent SARS-CoV-2 infection in a world-wide mobile application-based cohort. Our observation that healthcare workers experience a higher likelihood of infection has biological plausibility and fits with previous evidence.<sup>5</sup> Although disease transmission has been described from children<sup>6</sup> and may theoretically occur from pets,<sup>7</sup> these data suggest that each may be an independent risk factor for infection. A higher risk among dog owners may arise from environmental exposures during dog-walking or fomite-based exposure from dog petting.

Although previous evidence demonstrates a higher risk of infection among black and LatinX individuals,<sup>8</sup> here we found that Asians experience the lowest risk. A higher degree of education is commonly a protective factor against disease. The observation that recent marijuana smoking or vaping was associated with a lower risk was surprising—while it is possible this reflected “effect-cause” (for example, those feeling ill were less likely to use the drug), we did not find a similar association with e-cigarettes or smoking tobacco. While the flu vaccine would not be considered to confer cross-immunity with coronaviruses, the lower risk among those who received the flu shot could reflect more overall healthy behaviors or perhaps reflects a general immune system boost that renders individuals less prone to viral infection.

While a strength of the current study is that it was not constrained to individuals seeking medical care, we acknowledge that we cannot exclude residual or unmeasured confounding in this observational study and that our study population, all with smartphones, does not

**Table 1** Baseline Characteristics of Participants with and without a Positive SARS-CoV-2 Test for Active Infection

	<b>Tested Positive N=484</b>	<b>Everyone Else (Tested Negative, Not Tested) N=35,557</b>	<b>p-value</b>
<b>Primary Residence in USA</b>	461 (95.2%)	32,989 (92.8%)	0.033
<b>Median Age (IQR)</b>	42.0 (36.0–51.0) <sup>a</sup>	43.0 (35.0–54.0) <sup>b</sup>	0.17
<b>Female Biological Sex</b>	361 (75.8%)	23,163 (65.1%)	<0.001
<b>Race/Ethnicity</b>			<0.001
White	403 (84.7%)	28,902 (81.3%)	
Black	7 (1.5%)	336 (0.9%)	
Hispanic (any race)	47 (9.9%)	2581 (7.3%)	
Asian or Pacific Islander	10 (2.1%)	1919 (5.4%)	
Other (including multiracial)	9 (1.9%)	813 (2.3%)	
<b>Highest Level of Education</b>			<0.001
Less than high school	3 (0.6%)	164 (0.5%)	
High school graduate	27 (5.7%)	1356 (3.8%)	
College Graduate (including associate degree)	268 (55.4%)	17,552 (49.4%)	
Graduate school	171 (35.3%)	15,035 (42.3%)	
Other	7 (1.4%)	427 (1.2%)	
<b>Healthcare worker</b>	181 (37.4%)	7299 (20.5%)	<0.001
<b>Children living with you</b>	205 (42.4%)	11,529 (32.4%)	<0.001
<b>Children home from college living with you</b>	40 (8.3%)	2778 (7.8%)	0.67
<b>Any pets at home</b>	357 (73.8%)	22,882 (64.4%)	<0.001
<b>Cigarettes: any use in last 30 days</b>	25 (5.4%)	1906 (5.4%)	0.92
<b>E-cigarettes: any use in last 30 days</b>	13 (2.8%)	1041 (2.9%)	0.89
<b>Marijuana: any use in last 30 days</b>	31 (6.8%)	3300 (9.3%)	0.027
<b>Atrial fibrillation</b>	7 (1.5%)	952 (2.7%)	0.09
<b>Anemia</b>	54 (11.4%)	3512 (9.9%)	0.36
<b>Asthma</b>	52 (11.0%)	3482 (9.8%)	0.49
<b>Cancer</b>	14 (3.0%)	1023 (2.9%)	1.00
<b>Coronary artery disease</b>	8 (1.7%)	825 (2.2%)	0.45
<b>Congestive heart failure</b>	3 (0.6%)	220 (0.6%)	1.00
<b>Chronic obstructive pulmonary disease</b>	10 (2.1%)	569 (1.6%)	0.46
<b>Diabetes</b>	18 (3.8%)	1400 (3.9%)	0.91
<b>High blood pressure</b>	86 (18.1%)	6777 (19.1%)	0.48
<b>Human immunodeficiency virus</b>	4 (0.8%)	139 (0.4%)	0.13
<b>Immunodeficiency</b>	20 (4.2%)	701 (2.0%)	0.003
<b>Myocardial infarct</b>	3 (0.6%)	340 (1.0%)	0.64
<b>Pregnant</b>	10 (2.1%)	306 (0.9%)	0.011
<b>Sleep apnea</b>	45 (9.5%)	3578 (10.1%)	0.60

(Continued)

**Table I** (Continued).

	<b>Tested Positive N=484</b>	<b>Everyone Else (Tested Negative, Not Tested) N=35,557</b>	<b>p-value</b>
<b>Stroke</b>	5 (1.1%)	433 (1.2%)	1.00
<b>Received flu shot within the year</b>	352 (72.9%)	26,258 (73.8%)	0.64

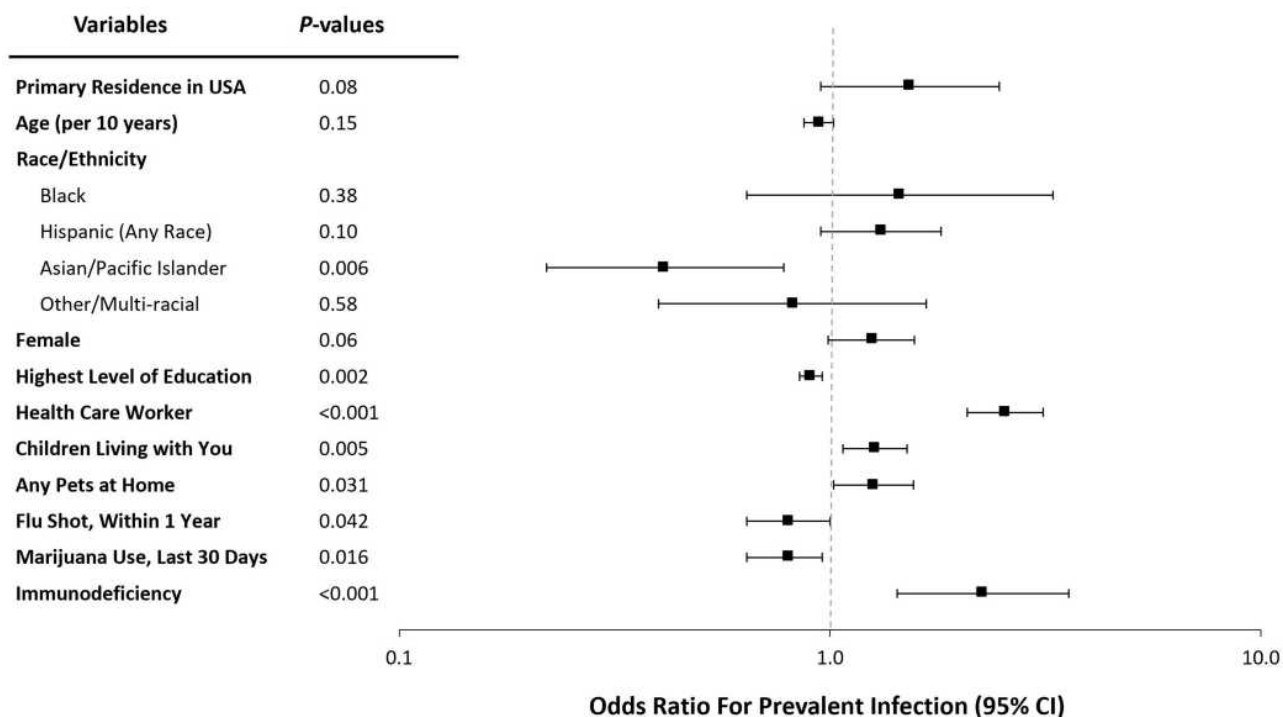
**Notes:** <sup>a</sup>The youngest and oldest ages of participants within the “Tested Positive” group was 18 years and 78 years, respectively. <sup>b</sup>The youngest and oldest ages of participants within the “Everyone Else” group was 18 years and 91 years, respectively.

necessarily reflect the general population. We also relied on interpretation from participants regarding what constituted a personal history of immunodeficiency, where immunodeficiency represents a broad phenomenon, though we included separate survey questions assessing a history of more specific immunosuppressive conditions such as for diabetes and human immunodeficiency virus (HIV). There is also the possibility that those who smoke or vape marijuana may have been less likely to receive SARS-CoV-2 testing, which could have ultimately contributed to the observed inverse relationship between smoking or vaping marijuana and prevalent SARS-CoV-2 infections. Furthermore, the analyses treated participants who were not tested for SARS-CoV-2

infection as if they had not been infected and we acknowledge that there may have been participants in this group with prevalent infections that were therefore under-ascertained. We do not believe this would have led to spurious false-positive results, but on the contrary, this may have led to underestimating the strengths of our observed relationships.

### Conclusion

In conclusion, we identified various characteristics and behaviors, many of which are potentially modifiable, that are associated with prevalent SARS-CoV-2 infection in a world-wide mobile application-based cohort. We believe that these findings will be broadly useful for targeted



**Figure 1** Forest plot of adjusted odds ratios for participants with prevalent positive SARS-CoV-2 test results. Race/ethnicity categories were compared against non-Hispanic white participants. Y error bars indicate 95% confidence intervals.

public health interventions in efforts to further contain the pandemic.

## Data Sharing Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## Disclosure

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