The US COVID-19 surveillance environment: An ecological analysis of the relationship of testing adequacy in the context of vaccination

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Abstract

Background: COVID-19 testing is a critical component of public health surveillance and pandemic control, especially among the unvaccinated, as the nation resumes in-person activities. This study examined the relationships between COVID-19 testing rates, testing positivity rates and vaccination coverage across US counties.

Methods: Data from the Health and Human Services' Community Profile Report and 2016-2020 American Community Survey 5-Year Estimates were used. 3,114 US counties were analyzed from January through September 2021. Associations among the testing metrics and vaccination coverage were estimated using multiple linear regression models with fixed effects for states and adjusted for county demographics. COVID-19 testing rates (PCR testing per 1,000), testing positivity (percentage of all PCR tests that were positive), and vaccination coverage (percentage county population that was fully vaccinated).

Results: Nationally, median daily COVID-19 testing rates were highest in January and September (35.5 and 34.6 tests per capita, respectively) and lowest in July (13.2 tests per capita). Monthly testing positivity was between 0.03 and 0.12 percentage points (pp) lower for each pp of vaccination coverage, and monthly testing rates were between 0.08 and 0.22 tests per capita higher for each pp of vaccination coverage.

Conclusions: The quantity of COVID-19 testing was associated with vaccination coverage, implying counties having populations with relatively lower protection against the virus are conducting less testing than counties with relatively more protection. Monitoring testing practices in relation to vaccination coverage may be used to monitor the sufficiency of COVID-19 testing based on population susceptibility to the virus.

Keywords

Covid-19; testing; test positivity; test per capita; vaccination

Introduction

Timely and efficient testing and contact tracing are cornerstones of infectious disease surveillance and outbreak response [1]. In the first year of the COVID-19 pandemic, large-scale testing was the primary strategy to initiate quarantine and isolation protocols to disrupt SARS-CoV-2 virus transmission and contain the pandemic [2,3]. Workplaces and educational institutions across the nation utilized routine testing as a method to identify cases and prevent further transmission while [4]. After the emergency use authorization of safe and effective COVID-19 vaccines in December 2020 [5], public health authorities focused on administering free-of-cost vaccinations nationwide as a primary means to protect the population. The emphasis on testing has since diminished. Nevertheless, nearly a year into the US vaccination campaign, two in five all Americans remains unvaccinated, vaccine coverage is highly geographically variable [6], and breakthrough infections have been reported among the vaccinated [7]. Thus, testing remains a key strategy to identify and isolate cases of COVID-19 to proactively prevent outbreaks, particularly in areas with low vaccination coverage [8]. We evaluate the dynamic relationship between vaccine coverage and metrics of COVID-19 testing in US states and counties in the first year of the COVID-19 vaccine roll-out.

Methods

Study Sample and Measures

We obtained daily COVID-19 testing and vaccination data for states and counties from the Health and Human Services Community Profile Report (CPR) from January 1st through September 30th 2021 [9]. The CPR compiles these data from the COVID-19 Electronic Lab Reporting system. Daily testing and vaccination data were used to derive two metrics of COVID-

19 testing and one metric of vaccine coverage at the nation-, state-, and county-levels. Of all 3,220 US counties included in the data, 107 counties were excluded from analyses due to missing information, yielding a final sample of 3,113 counties. Testing rates reflect the quantity of testing activities conducted by public health authorities, and maintaining low test positivity has been recommended as a measure of testing adequacy. The testing rate, or tests per 1,000 persons, was calculated as the number of tests per month divided by population size multiplied by 1,000. Testing positivity was calculated as the number of positive tests divided by number of tests by calendar month. Both testing metrics were restricted to viral RT-PCR tests; CPR does not include antigen and serology tests. Vaccination coverage was measured as the percentage of the total population that was fully vaccinated as of the midpoint of each month. According to CDC definitions, we considered full vaccination as two doses of the Pfizer or Moderna mRNA vaccine or a single dose of the Johnson & Johnson adenovirus vector vaccine [10]. County demographic characteristics were from the 2020 American Community Survey,[11] and included total population, percentage of population aged 65 years and older, average household income, and percentage of minority population. All data used in this study are publicly available.

Statistical analysis

We derived the monthly national distribution of testing rates and positivity, and vaccination. We estimated the state- and county-level correlations between testing rates, test positivity, and vaccination coverage by month. To examine unadjusted and adjusted associations between three measurements, we transformed daily CPR data into weekly data in which mean testing rates, test positivity and vaccination coverage were calculated. Then we fitted a linear regression model with fixed effects for state to examine the association between county-level test positivity and

testing rates, test positivity and vaccination coverage, and testing rates and vaccination coverage. We fitted unadjusted and adjusted linear mixed effects models. In unadjusted model, we only include fixed effects for state and we additionally controlled for other covariates including county-level total population, median household income, percentage of population aged 65 and over and percentage of black residents for adjusted models. All analyses were conducted using R statistical software, v.3.6.2.

Results

At the national level, median daily COVID-19 testing rates were highest in January and September (35.5 and 34.6 tests per 1,000, respectively) and lowest in July and June (13.2 and 14.3 tests per 1,000, respectively) (Table 1). Month-to-month trends in COVID-19 test positivity by month mirrored testing rates, such that test positivity peaked in January and August (11.5% and 10.2%, respectively). National-level cumulative vaccination coverage was 1.5% in January and reached 54.2% in September.

Figure 1 shows correlation between state- and county-level testing rates and test positivity. We found an inverse relationship between testing rates and test positivity in all months across states and counties. In addition, adjusted county-level regression analyses show that monthly county-level test positivity decreased by 0.02 (February, March, May and June) to 0.07 (September) percentage points (pp) for each additional test per capita after accounting for socioeconomic and demographic characteristics (Table 2). In both results, the relationship between testing rates and test positivity was stronger in January, August, and September in which test positivity and test per capita were highest.

County-level vaccination coverage was inversely associated with testing positivity (Table 2; Figure 2) and positively associated with testing rates (Table 2; Figure 3). Adjusted regression model shows that monthly test positivity was between 0.02 (July) and 0.12 (September) pp lower for each pp of the county population that was fully vaccinated. In contrast, the associations between county vaccination and testing rate were positive in all months and was highest in March (0.20 tests per 1,000; 95%CI: 0.14, 0.25) in which vaccination coverage in the county was lower than 40%.

Discussion

We investigated the relationship between COVID-19 testing metrics and vaccination across US states and counties by month from January 2021 to September 2021. Across counties, we observed an inverse relationship between testing rate and test positivity from January 2021 to September 2021, reiterating the potential role of test positivity as a metric to gauge the adequacy of the testing rate. In addition, we found that higher vaccination coverage was associated with decreased test positivity rates and increased tests per capita at county-level after adjustment for socioeconomic and demographic features. This suggests that COVID-19 testing lags behind in areas with relatively larger shares of unvaccinated individuals.

Vaccination has proven to be effective at mitigating the health harms of the virus, as the vast majority of patients hospitalized in regions of the U.S. for COVID-19 during the summer of 2021 were unvaccinated [7,12]. The unvaccinated population, however, has much to gain from COVID-19 testing. Among the unvaccinated, early detection of cases prevents further transmission of the virus and also provides an opportunity to administer therapies, such as

monoclonal antibodies [13,14], that prevent hospitalization if offered early in the disease course. Therefore, from a public health perspective, areas with lower vaccine uptake should more aggressively engage in testing for COVID-19 to prevent outbreaks and thus ensure safety in congregate settings such as schools and workplaces. In reality, the positive relationship between vaccination coverage and testing rates indicates that counties with less vaccinated populations were conducting less testing than counties with relatively more protection. Furthermore, counties with lower vaccination coverage had relatively higher test positivity. Together, these findings indicate potential insufficient testing among counties with larger shares of unvaccinated populations, which are more susceptible to the virus and severe outcomes.

Our study was conducted during the period when the Alpha (B.1.1.7; January to June) and Delta (B.1.617.2; July to September) variants were dominant. The Delta variant was first reported in Texas in May 2021, when national testing was at its nadir. Despite major variations in the levels of testing rates, testing positivity, and vaccination coverage across these months, we found that the *direction* of the relationship among vaccination and testing metrics was consistent across these periods. There were some variations in the magnitude of the association, such that the inverse relationships of tests per capita with test positivity and of vaccination coverage with test positivity were strong in the months when Delta was dominant. On the other hand, there was no consistent pattern in the magnitude of association between vaccination coverage and testing rate. The consistency of associations across differing variants suggests that associations between vaccination and testing were not dependent on the transmissibility of the variant as much as testing policies of states and testing behaviors of individuals.

We also found that the state-level association was stronger than county-level associations in all months. The stronger state-level associations may be due to more random variation in the

county-level, or because the state-fixed effects absorb the variability in behaviors related to COVID-19.

It is possible that studied associations have subsequently changed because of variants for which available vaccines are not as effective. For example, breakthrough infections among the vaccinated are more common with the Omicron variant (B.1.1.529), which emerged after the study period. This may decouple the association between vaccination and test positivity. Understanding whether new variants and resultant policy shifts impact the relationships studied may is an important topic for future research.

This study has some limitations. Testing data were not available by age, and we therefore opted to estimate all indicators among the entire county population, irrespective of age. While age-eligibility for vaccination changed over the study period, the denominator for vaccination coverage was not restricted by age. Nevertheless, analyses by study month allow for comparisons of associations at different stages of vaccination eligibility. Additionally, we expect there to be minimal bias in reported correlations because the measure of vaccination coverage accurately reflects the proportion of the total population that was immunized against COVID-19. Second, we were not able to account for access to testing and other non-pharmacological behaviors (such as masking) that may differ by county due to data limitation. Such factors may impact the relationships among vaccination and testing metrics. Third, the use of testing positivity as a measure of testing adequacy has limitations. During infectious disease outbreaks when there is a surge of new cases, testing positivity is expected to increase and it may not be realistic to increase the volume of testing proportionate to the size of the outbreak. However, the focus of this study was the associations among vaccination, testing rates, and testing positivity independent of case rates.

Conclusions

This study provides important information as states and counties continue to consider adequacy of current policies to mitigate the harms of COVID-19, especially as in-person activities resume. Maintaining adequate testing infrastructure *and* public awareness of the importance of testing is critical for appropriate public health response. Monitoring test positivity and testing rates in relation to vaccination coverage is an important strategy to guide adequate testing activities, coverage, and interpretation among communities that remain highly susceptible to the virus and as new and highly transmissible variants of the virus emerge (e.g., Omicron [15]).

Notes

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Potential Conflicts:

L.A.W. reports awards to Emory University from the National Institutes of Health (grants number 5R01AI125842-05, 75N92021C00012, and 1R01DA1DA052214) and honorarium payment to self and travel reimbursement from Global Burden of Disease Independent Advisory Committee. All other authors do not declare any conflicts of interest.

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Tables

Table 1. National-level median test positivity rates, total number of tests per 1,000 persons and percentage of population fully vaccinated by month

	Daily Test per 1,000		Daily Test positivity, %		Vaccination, %	
	Median	(Min, Max)	Median	(Min, Max)	Median	(Min, Max)
January	35.5	31.5, 39.6	11.5	8.5, 14.9	1.5	0.8, 3.4
February	27.7	24.2, 33.1	6.1	4.7, 8.4	4.5	3.4, 8.5
March	26.1	25.5, 27.6	4.3	4.1, 5.2	12.3	8.6, 16.4
April	26.3	25.3, 27.0	5.3	4.3, 5.5	23.9	16.9, 30.5
May	21.2	15.5, 25.2	3.1	2.2, 4.2	37.0	31.2, 40.8
June	14.3	12.4, 16.5	1.8	1.7, 2.3	44.0	40.9, 46.7
July	13.2	10.6, 19.0	5.4	2.5, 9.7	48.4	47.0, 49.5
August	27.6	19.2, 34.6	10.2	9.6, 10.4	50.8	49.6, 52.4
September	34.6	31.2, 36.3	8.0	6.3, 9.4	54.2	52.6, 55.9

Table 2. Association between county-level test positivity, test per 1000 and percentage of vaccination by month.

Outcome	**Test Positivity, %**				**Test Positivity, %**				**Testing rate, tests per 1000**			
Exposure	Test per 1,000				% Vaccination				% Vaccination			
	Unadjusted		Adjusted[a]		Unadjusted		Adjusted[a]		Unadjusted		Adjusted[a]	
	Coeff	95% CI	Coeff	95% CI	Coeff	95% CI	Coeff	95% CI	Coeff	95% CI	Coeff	95% CI
January	-0.05	-0.05, -0.06	-0.05	-0.06, -0.05								
February	-0.02	-0.02, -0.03	-0.02	-0.03, -0.02								
March	-0.02	-0.02, -0.03	-0.02	-0.03, -0.02								
April	-0.03	-0.03, -0.04	-0.03	-0.04, -0.03	-0.06	-0.07, -0.05	-0.06	-0.08, -0.05	0.18	0.13, 0.24	0.20	0.14, 0.25
May	-0.02	-0.02, -0.03	-0.02	-0.03, -0.02	-0.04	-0.05, -0.03	-0.03	-0.04, -0.02	0.14	0.11, 0.17	0.14	0.11, 0.17
June	-0.02	-0.01, -0.03	-0.02	-0.03, -0.01	-0.04	-0.05, -0.03	-0.03	-0.04, -0.02	0.08	0.05, 0.11	0.07	0.04, 0.10
July	-0.04	-0.03, -0.04	-0.04	-0.04, -0.03	-0.01	-0.02, -0.01	-0.02	-0.01, -0.03	0.13	0.09, 0.17	0.10	0.06, 0.14
August	-0.04	-0.02, -0.05	-0.03	-0.04, -0.01	-0.10	-0.11, -0.08	-0.07	-0.09, -0.06	0.16	0.14, 0.17	0.13	0.11, 0.15
September	-0.08	-0.06, -0.10	-0.07	-0.09, -0.04	-0.16	-0.19, -0.13	-0.12	-0.15, -0.09	0.17	0.13, 0.21	0.15	0.10, 0.19

Note: Coefficients of percentage of fully vaccinated persons are presented for April through September because county-level vaccination data between January and March are not available. [a]County-level fixed-effect regression coefficient estimating test positivity rate from test per 1,000 with adjustment for county-level total population, median household income, % population aged 65 and over and % black residents with state fixed effects.

Figure legends

Figure 1. State- and county-level COVID-19 test positivity and testing rate by month.
Note: Grey circles and lines present county-level values. Red circles and lines present state-level values. Coef: Coefficient of test per 1,000 from county-level fixed-effect regression model presented in Table 2.

Figure 2. State- and county-level COVID-19 test positivity and vaccination coverage by month.
Note: Vaccination: percent of fully vaccinated population. Grey circle and line represent are at county-level. Red circle and line represent are at county-level. Data of county-level percentages of vaccination were not available in January, February and March of 2021. Coef: Coefficient of percent of fully vaccinated population from county-level fixed-effect regression model presented in Table 2.

Figure 3. State- and county-level COVID-19 testing rate and vaccination coverage by month.
Note: Vaccination: percent of fully vaccinated population. Grey circle and line represent are at county-level. Red circle and line represent are at county-level. Data of county-level percentages of vaccination are not available in January, February and March of 2021. Coef: Coefficient of percent of fully vaccinated population from county-level fixed-effect regression model presented in Table 2.

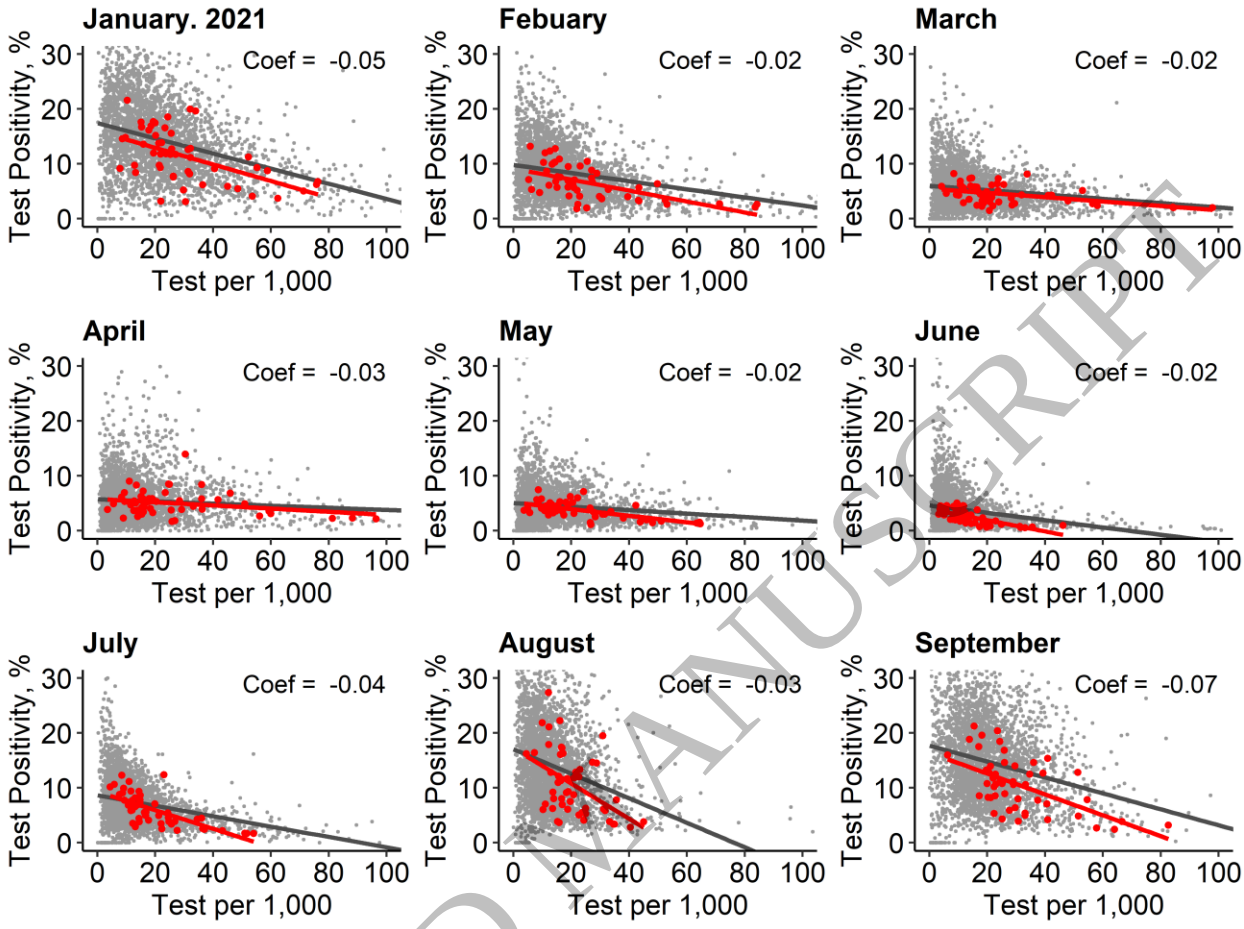

Figure 1
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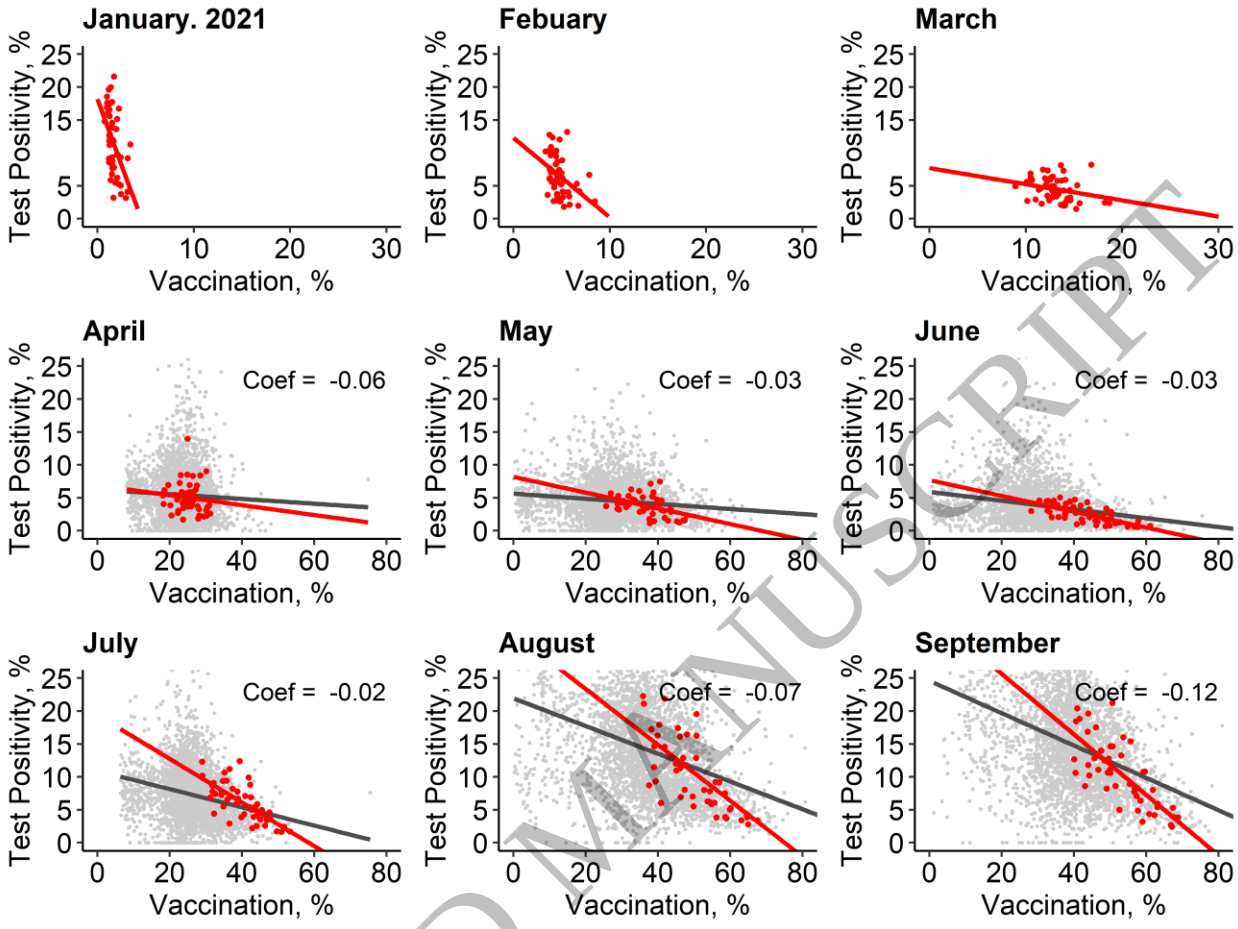

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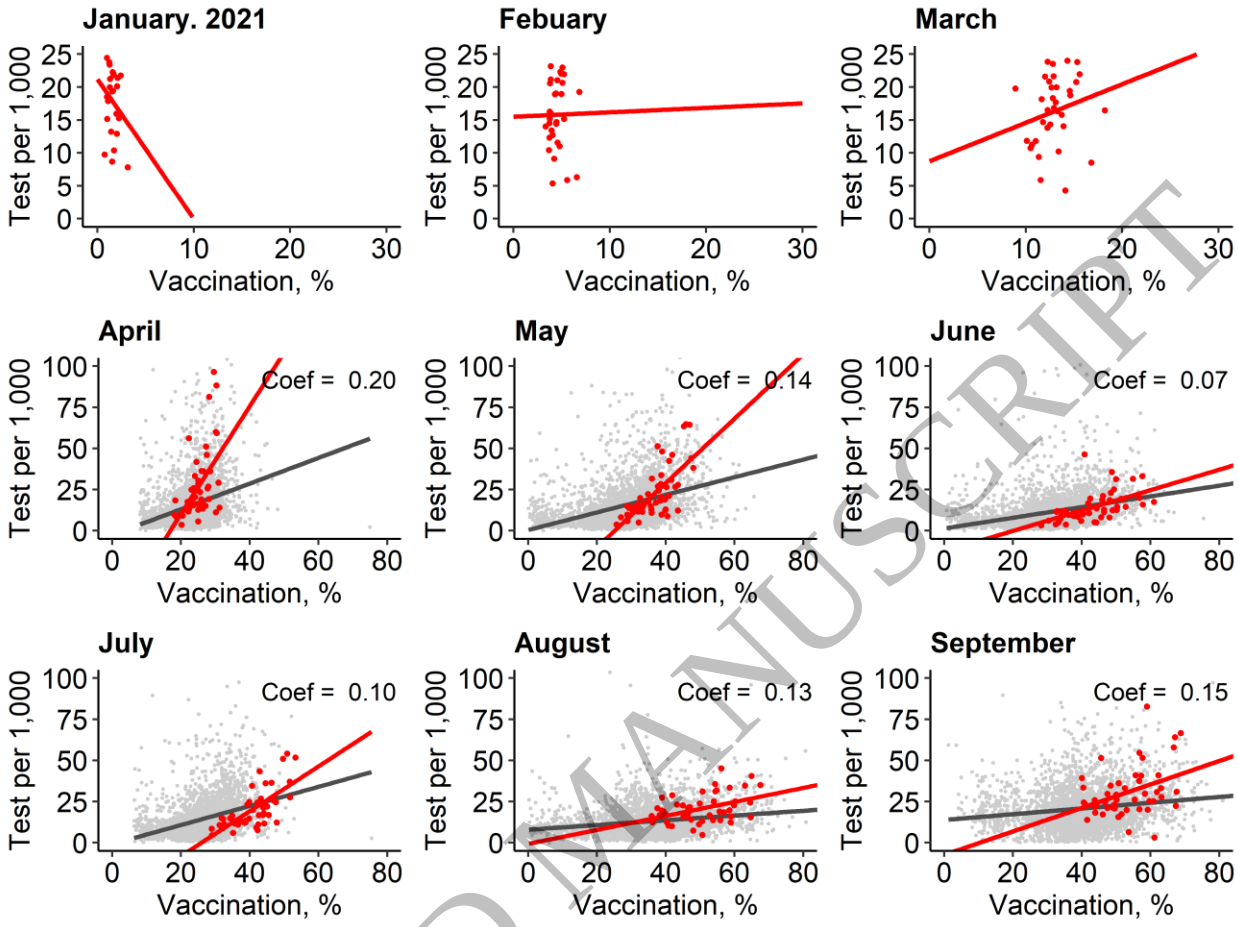

Figure 3
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