

Title: The Impact of State Mask-Wearing Requirements on the Growth of COVID-19 Cases, Hospitalizations, and Deaths in the United States

Authors: Peter F. Rebeiro, PhD, MHS^{1,2}; David M. Aronoff, MD¹; M. Kevin Smith, MD, PhD, MMHC¹

Affiliations:

1. Vanderbilt University School of Medicine, Department of Medicine
2. Vanderbilt University School of Medicine, Department of Biostatistics

Corresponding Author:

Peter F. Rebeiro, PhD, MPH

1161 21st Ave. S.

A-2200 MCN

Nashville, TN 37232

Tel: 615-343-8351

Fax: 615-343-6160

Email: p.rebeiro@vumc.org

ABSTRACT

In ecologic analyses of US states, piecewise multivariable models showed lower post- vs. pre-mask requirement case-rate slopes, with -1.0% (95%CI: -1.34%, -0.57%) and -0.44% (95%CI: -0.86%, -0.03%) per 100,000 per day among early- and late- versus never-adopter states, respectively. Our findings support statewide mask requirements to mitigate COVID-19 transmission.

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INTRODUCTION

Evidence supports the use of cloth face coverings (“masks”) in reducing person-to-person spread of COVID-19^{1,2}. We analyzed the impact of state-wide mask requirements on new COVID-19 cases/100,000 population/day from the beginning of the US pandemic until October 31, 2020 using the staggered and incomplete implementation of mask requirements at the state level as a quasi-experimental design.

METHODS

We performed an ecologic study on US residents at risk of COVID-19 diagnosis using the 7-day average of new confirmed positive COVID-19 cases daily from January 1, 2020 to October 31, 2020 as the primary outcome; 7-day averages of new COVID-19-related hospitalizations and COVID-19 cause-specific deaths daily during the same period were included as secondary outcomes.³ The timing and status of statewide masking requirements constituted the exposure of interest^{4,5}. COVID-19 cases were standardized per 100,000 population, and hospitalizations and deaths per 1,000,000 population, per day by state.⁶

We attempted to mitigate potential bias resulting from measurement error around the exposure by stratifying state mask requirement implementation as “early” (pre-June 12), “late” (post-June 12), and “never” adopters, based on interstate inflections in the case-growth curves (Figure, panel A). States that experienced early transmission surges in the winter and spring of 2020 were therefore not treated equivalently to those experiencing a later acceleration in transmission during the summer of 2020, during a period which coincided with much more stringent anti-COVID measures in states that had implemented and exited aggressive lockdowns earlier on.^{2,7} Additional confounding and interstate differences by the proportion of state residents aged ≥ 75 years, living below the Federal poverty line, uninsured, and of Black race, as well as the total population density per square mile, were also accounted for⁶. We chose these factors *a priori* based on availability of measures across all 50 states, potential

variation across states, and prior literature indicating disparities in COVID-19 case growth, hospitalization, and mortality across the distribution of these factors.⁸⁻¹¹

We assessed distributional differences in case rates between masking categories using the Kruskal-Wallis test. Though only available in the final months of the study period, we also described differences in the adjusted average percentages of facebook users who say they use masks “most or all of the time” using multivariable linear regression stratified by state mask requirement category and adjusting for potential confounders; these survey data were collected by the Delphi Group at Carnegie Mellon University and are publicly available.¹² We performed multivariable and piecewise Poisson regressions of daily COVID-19 rates on mask requirement status, clustered by state, using robust standard errors. For the primary multivariable model, we fit interactions between mask requirement status (early vs. never; late vs. never) and mask requirement period (post- vs. pre-requirement), similar to a difference-in-difference estimator. For the piecewise model, we fit separate intercepts and slopes in the pre- and post-requirement periods and included interactions between mask requirement status and period to model slopes flexibly between states in each period. For “never” adopting states, the pre-/post- periods were defined using the “early”/“late” demarcation date of June 12 as time-0. In secondary analyses, we fit a multivariable Poisson regression during only the most recent wave of infections across all states (after September 12) by mask requirement status.

RESULTS

Among 50 states and the District of Columbia, there were 15 (29%) early mask requirement adopters, 19 (37%) late adopters, and 17 (33%) never adopters. The median COVID-19 rates per 100,000 in the post-requirement period were 7.53 (interquartile range [IQR]: 4.05, 12.02), 12.70 (IQR: 8.91, 18.96), and 16.06 (IQR: 9.45, 25.32) cases/day, respectively ($p < 0.01$). The dose-response pattern was similar for median hospitalization rates per 1 million (2.34, IQR: 0, 7.40 for early adopters; 4.17, IQR: 0, 8.28 for late adopters; 7.31, IQR: 3.12, 10.82 for never adopters; $p < 0.01$) though not for median death rates per 1 million

(1.59, IQR: 0.76, 3.24 for early adopters; 1.91, IQR: 1.13, 3.09 for late adopters; 1.78, IQR: 0.97, 3.30 for never adopters).

The mean trajectories of COVID-19 case rates were divergent between all groups, particularly for early vs. never adopter states in the more recent post-requirement period (Figure, panel A). In the final month of the study period, when survey data on statewide public mask use were available, consistent mask use, as assessed through self-report, was higher in both early (unadjusted median of 92.9%; adjusted mean difference of +10.2%) and late (unadjusted median of 87.2%; adjusted mean difference of +7.1%) compared to never adopter states (unadjusted median of 81.5%) (Figure, panel B).

In models accounting for potential confounders and interactions between mask requirement status and period, there was a strong protective effect comparing case rates in early to never adopter states (adjusted ratio of incidence rate ratios [aIRRR]=0.15, 95% confidence interval [CI]: 0.10, 0.24); the magnitude and direction of the association indicated a smaller protective effect comparing late to never adopter states in the post- vs. pre-mask requirement periods (aIRRR=0.76, 95% CI: 0.53, 1.09), and though the confidence interval was largely in the same protective direction, it did contain the null. When comparing hospitalization rates to those in never adopter states, there was a similarly strong protective effect for early adopter states (aIRRR=0.17, 95% CI: 0.06, 0.42), but an essentially null result for late adopter states (aIRRR=0.72, 95% CI: 0.42, 1.25). For death rates, there was again a strong protective effect comparing early to never adopter states (aIRRR=0.10, 95% CI: 0.06, 0.17), but in contrast to the effect for the primary outcome of cases, there remained a strong protective effect when comparing death rates in late to never adopter states (aIRRR=0.57, 95% CI: 0.35, 0.93).

Piecewise models, adjusted for confounders, showed pronounced contrasts in slopes for the primary outcome in the post-mask requirement period, with lower daily case rates of -1.0% per day (95% CI: -1.34%, -0.57%) among early and -0.44% per day (95% CI: -0.86%, -0.03%) among late compared to never adopter states (Figure, panel C). During the most recent period

of case growth, risk of COVID-19 was 58% lower among early (adjusted incidence rate ratio [aIRR]=0.42, 95% CI: 0.26, 0.68) and 43% lower among late (aIRR=0.57, 95% CI: 0.36, 0.91) versus never adopter states.

DISCUSSION

Multiple robust analyses quantifying changes in average COVID-19 case, hospitalization, and death rates attributable to mask policy changes in US states, using multiple methods, showed converging inferences. After adjusting for interstate differences in several characteristics, effects of early versus never adopting mask requirements were strongest, while effects of later mask requirements were more dilute, though generally protective. Over the more recent period of case growth in this study, there were strong and significant effects related to slower increases in cases among early and late versus never adopter states.

There remain some limitations in the present study, particularly around the availability of well-measured individual-level confounders and effect modifiers of state mask policies. We did endeavor to include strong confounders, associated with policy differences across states and with disparities in COVID-19 outcomes that have been noted in the literature, though the list is not necessarily exhaustive.⁹⁻¹¹ The timing of additional mitigation measures implemented at various times throughout the past year was also only sparsely available across states during the study period. For the most part, such measures were implemented on county-by-county or city-by-city bases instead of statewide, making their incorporation in state-level analyses across the country (without inducing extensive missingness) untenable. Further, we were unable to assess mechanisms and possible mediation of mask policies in their impacts on COVID-19 case growth, hospitalizations, and deaths, primarily due to a paucity of data on, for example, actual mask use within statewide populations following mask policy implementation in a large number of states. Finally, though we have used multiple models to triangulate evidence, the model assumptions of traditional difference-in-difference or interrupted time series analyses may not be met here. These include, most importantly, that the outcome trajectories between never- and

early-/late-mask adoption states in the pre-intervention period were parallel (i.e., the parallel trends assumption), and that the outcome trajectories would have continued along the same path from the pre-intervention to post-intervention periods in the absence of the intervention (i.e., assumptions about counterfactual trends). As state-level policies have changed rapidly, not always in tandem with one another, and the dynamics of transmission have shifted rapidly throughout the past year, it may be difficult to meet these assumptions in this particular quasi-experimental design. That said, from the data available and the adjusted models we employed, it appears that multiple assumptions for these commonly-employed policy-evaluation models may have been plausibly satisfied. Indeed, it is as likely that the estimates we derived for the impact of mask policies on multiple COVID-19 outcomes are conservative, given the potential measurement error of the exposure due to county- and city-level mitigation efforts that may have taken place in late- and never-adopter states (in both the pre- and post-mask-policy periods).

Due to the rigor and multiplicity of our analyses, however, we believe this work addresses several possible barriers to inference and advances the scientific evidence showing positive and protective impacts of statewide mask requirements in the US.

ACKNOWLEDGMENTS

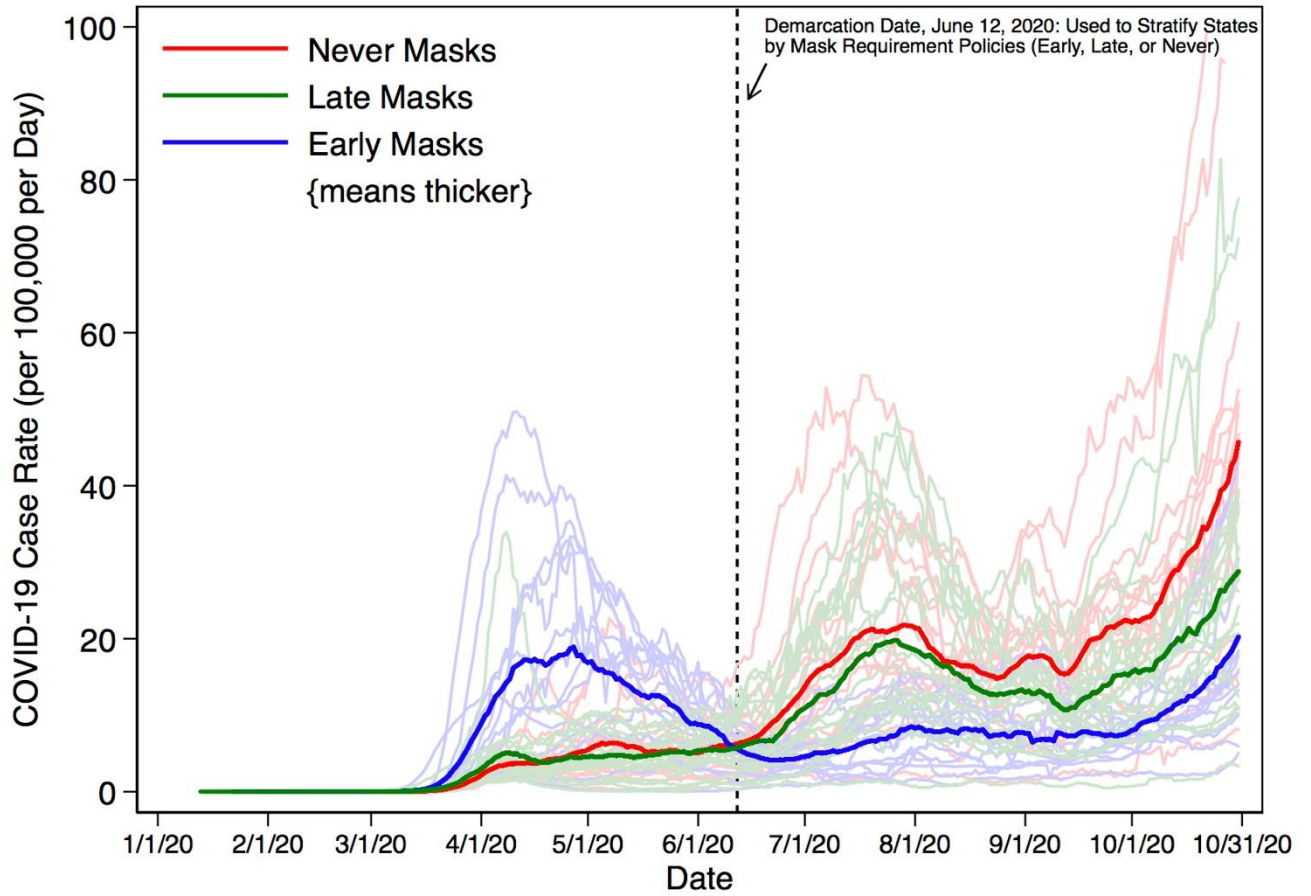
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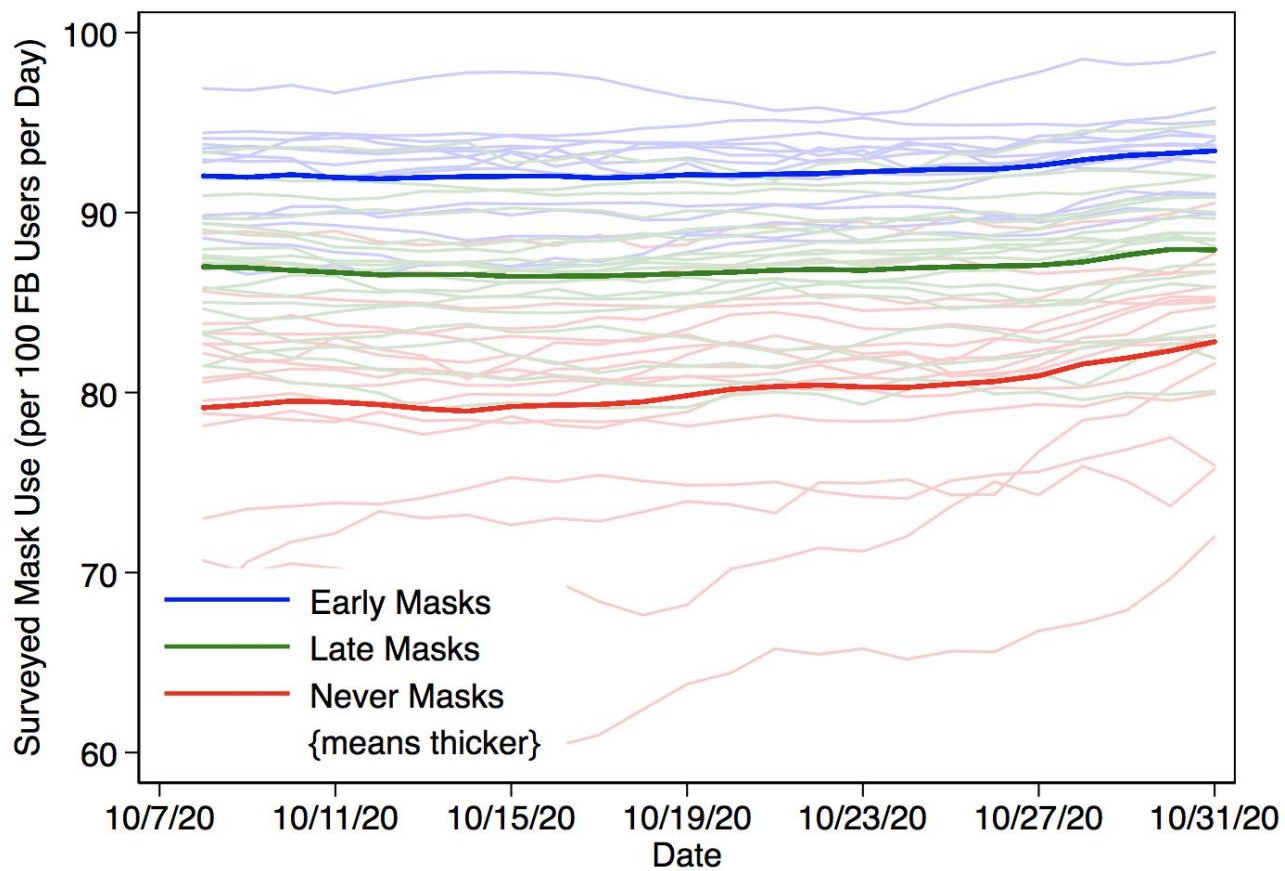
Figure. (A.) Daily COVID-19 case rates (per 100,000 population), stratified by statewide mask requirement timing; (B.) Frequency of mask use stratified by early, late, and never mask requirement status, using publicly available individual-level survey data from the final month of the study period; (C.) Adjusted predictions from multivariable piecewise Poisson regression including separate intercept and slope terms for the COVID-19 case rate (per 100,000 population per day) among early or late mask requirement adopting states (vs. never adopters) in the post- vs. pre-requirement periods. Statewide mask requirement timing was categorized using a common inflection point in case growth across all states of June 12, 2020, before which states were “early” adopters, after which they were “late” adopters (“never” adopters have not yet adopted statewide mask requirements).

A.



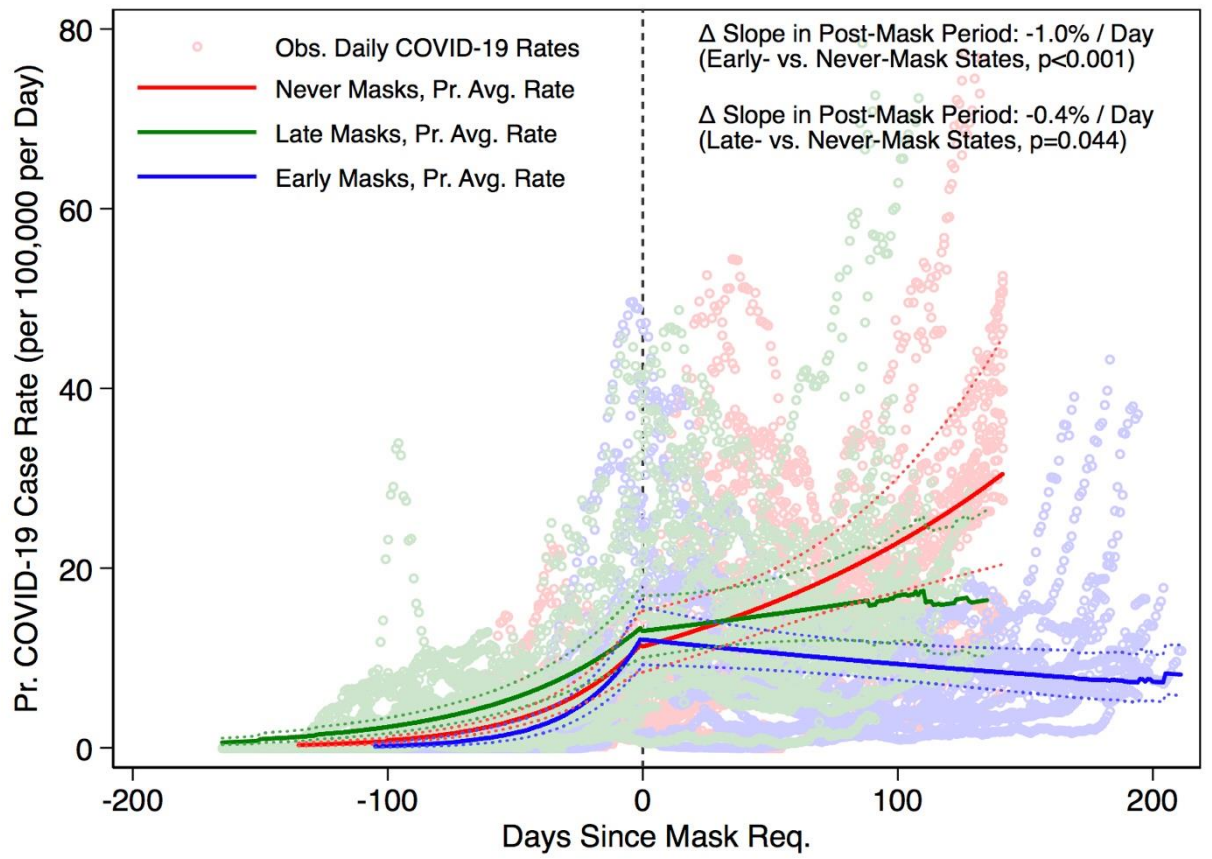
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