

1 **Mask mandate and use efficacy in state-level COVID-19 containment**

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9

10 **Abstract**

11 *Background:* Containment of the COVID-19 pandemic requires evidence-based strategies to reduce transmission.

12 Because COVID-19 can spread via respired droplets, many states have mandated mask use in public settings.

13 Randomized control trials have not clearly demonstrated mask efficacy against respiratory viruses, and

14 observational studies conflict on whether mask use predicts lower infection rates. We hypothesized that statewide

15 mask mandates and mask use are associated with lower COVID-19 case growth rates in the United States.

16 *Methods:* We calculated total COVID-19 case growth and mask use for the continental United States with data from

17 the Centers for Disease Control and Prevention and Institute for Health Metrics and Evaluation. We estimated post-

18 mask mandate case growth in non-mandate states using median issuance dates of neighboring states with mandates.

19 *Results:* Case growth was not significantly different between mandate and non-mandate states at low or high

20 transmission rates, and surges were equivocal. Mask use predicted lower case growth at low, but not high

21 transmission rates. Growth rates were comparable between states in the first and last mask use quintiles adjusted for

22 normalized total cases early in the pandemic and unadjusted after peak Fall-Winter infections. Mask use did not

23 predict Summer 2020 case growth for non-Northeast states or Fall-Winter 2020 growth for all continental states.

24 *Conclusions:* Mask mandates and use are not associated with slower state-level COVID-19 spread during COVID-

25 19 growth surges. Containment requires future research and implementation of existing efficacious strategies.

26

27 **Keywords:** COVID-19, SARS-CoV-2, face covering, medical mask, mask mandate, nonpharmaceutical intervention

28 **Introduction**

29 Since being linked to SARS-CoV-2 in early 2020, COVID-19 has increased mortality and induced
30 socioeconomic upheaval worldwide [1]. Typical COVID-19 symptoms mirror influenza, with loss of taste
31 and smell being differential indicators [2]. Age, obesity, cardiovascular disease, and diabetes are
32 associated with severe COVID-19 symptoms (e.g., pneumonia, blood clots, cytokine storm) and hence
33 higher risks of hospitalization and death [3, 4]. Given the incidence of comorbidities, evidence-based
34 containment strategies are warranted. Respirated droplets and aerosols containing SARS-CoV-2 are
35 intuitively likely modes of community transmission [5]. To reduce COVID-19 spread, governments have
36 issued mandates to wear medical masks or cloth face coverings (henceforth *masks*) in public settings. 40
37 of the United States have issued mask mandates since April 2020. Mask mandates have limited precedent,
38 making efficacy unclear. Therefore, our first objective was to evaluate the efficacy of mask mandates in
39 attenuating COVID-19 case growth at the state level.

40
41 Prior studies have conflicted on whether masks reduce SARS-CoV-2 transmission. For USS Theodore
42 Roosevelt crew, reported mask use was lower among COVID-19 cases (56% vs. 81%) [2]. There were no
43 infections for 47.9% of patrons of two hair stylists with COVID-19 with universal masking [6], but PCR
44 tests were not obtained for the other 52.1% of patrons [6], and first wave COVID-19 hospitalizations were
45 no higher in public schools (high density with minimal masking) than elsewhere in Sweden [7]. A
46 randomized controlled trial (RCT) of Danish volunteers found no protective benefit of medical masks
47 against COVID-19 infection [8]. In RCTs before COVID-19, viral infections were more common for
48 Vietnamese clinicians with cloth masks than medical or no masks (which were indistinguishable from
49 each other) [9], and N-95 respirators (but not medical masks) protected Beijing clinicians from bacterial
50 and viral diseases compared to no masks [10]. To be sure, mask use compliance in RCTs is not always
51 clear [11]. Mask use was 10% and 33% for Beijing households with and without intrahousehold COVID-
52 19 transmission, respectively [12]. This suggests greater mask use may reduce COVID-19 spread. Hence,

53 our second objective was to assess whether COVID-19 case growth is negatively associated with mask
54 use.

55
56 Earlier studies have not compared COVID-19 case growth rates in states with and without mandates, and
57 effects of compliance (proportion of people masked) are not clear. We assessed if statewide mask
58 mandates and compliance predict (and thus potentially decrease) statewide COVID-19 growth rates after
59 1 June 2020, when test capacity reached a threshold for minimal contact tracing [13]. We found little to
60 no association between COVID-19 case growth and mask mandates or mask use at the state level. These
61 findings suggest that statewide mandates and enhanced mask use did not detectably slow COVID-19
62 spread. We conclude by affirming the need for evidence-based strategies to minimize COVID-19 related
63 morbidity and mortality and briefly discussing mechanisms of spread.

64

65 **Materials and methods**

66 *Data Sources and Terms*

67 We obtained total COVID-19 cases up to 6 March 2021 for the 50 United States from the Centers for
68 Disease Control and Prevention (CDC) [14]. Total cases include confirmed and probable cases as defined
69 by the Council of State and Territorial Epidemiologists. Briefly, confirmed cases require PCR
70 amplification of SARS-CoV-2 RNA from a patient specimen. Probable cases require one of the
71 following: clinical and epidemiologic evidence, clinical or epidemiologic evidence supported by COVID-
72 19 antigen detection in respiratory specimens, or vital records listing COVID-19 as contributing to death.
73 Statewide mask mandates were emergency executive public health orders that require nose and mouth
74 coverings in public settings (including but not limited to retail locations) in more than 50% of counties
75 within a state [15, 16]. Mandate issuance dates were obtained from state health departments and press
76 releases. Early and late mandates were issued before and after 2 August 2020, respectively. Non-mandate
77 states did not have statewide orders as of 6 March 2021.

78 Mask use is defined as the percentage of people who always wear masks in public settings. We assessed
79 mask use with the University of Washington Institute for Health Metrics and Evaluation (IHME) COVID-
80 19 model site [17], which estimates mask wearing from Premise, the Facebook Global Symptom Survey
81 (University of Maryland), the Kaiser Family Foundation, and the YouGov Behavior Tracker Survey.
82 To identify regional patterns of COVID-19 case growth, we grouped states into five categories: Northeast
83 (Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York,
84 Pennsylvania, Rhode Island, and Vermont); Midwest (Illinois, Indiana, Iowa, Kentucky, Kansas,
85 Michigan, Minnesota, Missouri, Ohio, West Virginia, Wisconsin); Mountains-Plains (Colorado, Idaho,
86 Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Utah, Wyoming); South
87 (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina,
88 Tennessee, Texas, Virginia); and Pacific (Alaska, Arizona, California, Hawaii, Nevada, Oregon,
89 Washington).

90

91 *Parameter Derivation*

92 We calculated COVID-19 case parameters from total cases per 100,000 state residents (normalized total
93 cases; **Worksheet A in S1 Table**). As infectious diseases such as COVID-19 exhibit exponential growth,
94 we used logarithmic transformation to quantify daily case growth as shown elsewhere [15, 18]:

$$95 \frac{\text{case growth}}{\text{day}} = 100 * \left(\ln \frac{C_x}{C_{x-1}} \right)$$

96 Where C_x is normalized cases on a particular day and C_{x-1} is normalized cases on the prior day. To reduce
97 effects of reporting lags, we used a 7-day simple moving mean.

98 For each state, growth minima and maxima were the 20-day mean lowest and highest cases/day between
99 the end of the Summer infection wave and the height of the Fall-Winter infection wave. *Surge* refers to
100 the difference between maximal and minimal growth rates (the magnitude of growth rate increase) for
101 each state. *Surge rate* refers to the speed at which case growth increased from minimal to maximal levels
102 for each state (Surge/days between minima and maxima), normalized to the mean surge rate for all states.

103 Cases or masks at minima and maxima were the 20-day mean number of cases/100,000 state residents or
104 mask use for each state at its growth extrema. Change in masks refers to the percent increase in mask use
105 between extrema for each state.

106 To model post-mask mandate case growth in the 48 contiguous states (excluding Alaska and Hawaii), we
107 calculated the difference of natural logarithms of normalized total cases between 6 March 2021 (C_{306}) and
108 the date of mandate issuance (C_M) for each state with an early mandate:

$$109 \quad \textit{Post Mandate Growth} = \ln \frac{C_{306}}{C_M}$$

110 For states with late or no mandates, effective dates were modeled as medians of issuance dates among
111 bordering states with early mandates. For example, the effective mandate issuance date of Tennessee was
112 the median of issuance dates among the early mandate states Kentucky, Arkansas, Alabama, North
113 Carolina, and Virginia.

114 We reported mask use for Summer (1 June-1 Oct 2020) and Fall-Winter (1 Oct 2020-1 Mar 2021) as
115 mean mask use during these periods for each state. Cases on 1 June or 1 Oct were the 20-day mean
116 number of cases/100,000 on these two dates. Summer and Fall-Winter case growth were defined as
117 differences of natural logarithms of normalized total cases at the beginning and end of each period:

$$118 \quad \textit{Summer Growth} = \ln \frac{C_{1001}}{C_{601}} \quad \textit{Fall/Winter Growth} = \ln \frac{C_{301}}{C_{1001}}$$

119

120 *Statistics*

121 We used Prism 9.1 (GraphPad; San Diego, CA) to construct figures and perform null hypothesis
122 significance tests (**Worksheet D in S1 Table**). The significance threshold for all tests was $p < \alpha=0.05$. All
123 datapoints are state-level values, and we performed D'Agostino-Pearson tests to assess normality of
124 residuals.

125 To evaluate mask mandate efficacy, we performed two-tailed, two-sample t-tests (early vs. no mandates)
126 or ordinary one-way ANOVA with Holm-Šídák posttests (early vs. late vs. no mandates) and used
127 Welch's correction for heteroscedastic data. For non-normal data, we performed Mann-Whitney U tests

128 (early vs. no mandates) or Kruskal-Wallis with Dunn posttests (early vs. late vs. no mandates). This
129 decision tree conforms with recommended practices for datasets with $N > 5$ [19]. Hawaii was excluded
130 because its dates of extrema deviated from those of continental US states. Alaska and Hawaii were
131 excluded from post-mandate case growth assessment because they lack contiguous US border states.
132 To determine top and bottom mask use quintiles, we ranked mean mask use among states (excluding
133 Hawaii) from 1 June 2020 to 1 March 2021. For t tests comparing top and bottom quintiles, we assessed
134 days between the indicated normalized case totals and mean mask use over this interval for each state.
135 To evaluate mask use efficacy at and between extrema, we performed simple linear regressions with null
136 hypotheses of zero slope. We similarly evaluated mask use efficacy during the Summer and Fall-Winter
137 infection waves. For the Summer wave, Northeast states were excluded because they deviated from other
138 states with respect to covariation between normalized cases and growth. For the Fall-Winter wave,
139 Hawaii was excluded because it deviated from other states with respect to covariation between
140 normalized cases and growth. Infectious disease research commonly uses OLS [20, 21], with simple
141 linear and simple ln-linear models reported in recent COVID-19 studies [22, 23]. We used ordinary least
142 squares (OLS) for homoscedastic data and weighted least squares (WLS) for heteroscedastic data, as
143 determined by the GraphPad Prism Test for Homoscedasticity. Regardless of statistical significance, R^2
144 values denote coefficients of determination for lines of best fit with unconstrained slopes.

145

146 **Results**

147 *COVID-19 growth rates vary with time*

148 Normalized COVID-19 cases increased more than 1500-fold from March 2020 to March 2021 in the
149 United States [14]. To identify patterns of COVID-19 spread, we quantified case growth for each of the
150 50 US States (**Worksheet B in S1 Table**). Natural log (Ln)-linear plots revealed six phases of COVID-19
151 growth up to 6 March 2021: first wave (before May 2020), first minimum (May-June 2020), Summer

152 wave maximum (June-August 2020), second minimum (August-October 2020), Fall-Winter wave
153 maximum (October-January 2020), and third minimum (March 2021) (**S1-3 Figs**).

154

155 *Mandates are not associated with state COVID-19 case growth*

156 We next assessed associations between mask mandates and case growth. 33 US states issued statewide
157 mask mandates on or before 2 August 2020 (early), when case growth was low, while 7 other states
158 issued mandates after this date (late). We observed a six-phase pattern in states with early (**S1 Fig**), late
159 (**S2 Fig**), and no mask mandates (**S3 Fig**). This suggests qualitatively comparable courses of viral spread
160 among states regardless of mask mandates.

161

162 A recent study reported negative association between statewide mask mandates and subsequent COVID-
163 19 log growth rates [15]. We hypothesized that case growth would be lower in states with mandates. 64%
164 of early state mandates were issued during the Summer wave, which precluded determination of whether
165 mandates were associated with lower Summer wave case growth. We therefore examined case growth
166 after mandate issuance during the second minimum and the Fall-Winter wave maximum (henceforth
167 *minimum* and *maximum*) (**Fig 1A**). Hawaii was excluded because its minimum and maximum did not
168 chronologically align with continental states. Average Fall-Winter mask use was ~10% higher in early
169 mandate states than in late and no mandate states (Holm-Šídák $p \leq 0.001$; **Fig 1B**), confirming that
170 mandates promote greater mask use. Contrary to our hypothesis, early mandates were not associated with
171 lower minimum case growth (Mann-Whitney $p = 0.087$; **Fig 1C**). Maximum case growth was the same
172 among states with early, late, and no mandates (ANOVA $p = 0.29$; **Fig 1D**). This indicates that mask
173 mandates were not predictive of slower COVID-19 spread when community transmission rates were low
174 or high. We wondered if mask mandates were associated with smaller or slower surges in case growth.
175 Differences between minimum and maximum case growth were similar among early, late, and no
176 mandate states (ANOVA $p = 0.12$; **Fig 1E**), and surges from minimum to maximum growth occurred at

177 similar rates (ANOVA $p=0.16$; **Fig 1F**). These findings suggest that mask mandates are not predictive of
178 smaller or slower shifts from low to high case growth.

179
180 Normalized COVID-19 cases as of 6 March 2021 were 18.6% lower in states with early mandates than
181 states without mandates (Holm-Šídák $p=0.036$), but early mandates were issued over a range of dates (15
182 April to 2 August 2020). To assess how early mandates relate to cumulative cases, we calculated
183 normalized case growth for contiguous states between early mandate issuance and 6 March 2021. For
184 states with late and no mandates, we expressed effective dates (when states could have reasonably issued
185 mandates) as median dates of neighboring early mandate states. We expected to find lower case growth
186 among early mandate states. Surprisingly, normalized case growth after mandates (actual and effective)
187 were indistinguishable among state groups (ANOVA $p=0.93$; **Fig 2A**). Moreover, growth curves after
188 actual and effective mandates were not distinguishable among state groups at any date between mandate
189 issuance and 6 March 2021 (**Fig 2B**). Together, these data do not support an association between
190 statewide mandates and COVID-19 spread.

191
192 *Mask use is not associated with most state COVID-19 case growth*

193 We speculated that statewide mask use, rather than mask mandates per se, may predict COVID-19 case
194 growth. The University of Washington IHME provides robust estimates for mask use (defined as the
195 percentage of people who always wear masks in public settings) [17]. Mask use was associated with
196 lower minimum case growth (WLS $p<0.0001$; **Fig 3A**), but not normalized total cases at minima (OLS
197 $p=0.54$; **S4 Fig**). States with the highest first wave normalized cases and July 2020 seroprevalence were
198 primarily in the Northeast [14, 24], which could explain the lack of Summer growth in these states.
199 Excluding Northeast states, normalized cases predicted lower minimum case growth (WLS $p=0.001$; **S4**
200 **Fig**). Eight Northeast states were among the 10 states with highest mean mask use [17]. Intriguingly,
201 normalized cases grew from 400 to 1350 per 100,000 at similar rates between the first and last 10 states
202 for mask use (unpaired t test $p=0.49$), albeit ~50 days later for the last 10 states (**Fig 3B**). These findings

203 suggest the link between masks and minimum growth may be an artifact of the tendency for faster case
204 growth to occur at lower case prevalence. In support of this, we found no association between mask use
205 and case growth at maxima (OLS $p=0.11$; **Fig 3C**), when case prevalence differences were smaller among
206 states. There was also no association between mask use and normalized cases at maxima (OLS $p=0.073$;
207 **S5 Fig**), although residuals were slightly non-normal. The 10 states with highest and lowest mask use
208 exhibited indistinguishable growth rates from 0 to 80 days after maxima (Mann-Whitney $p=0.85$; **Fig**
209 **3D**), and higher normalized cases predicted lower maximum growth rates among continental states (OLS
210 $p<0.0001$; **S5 Fig**). While there was unexpected weak association between mask use and surge size (OLS
211 $p=0.03$; **Fig 3E**), mask use at minima did not predict surge rate (OLS $p=0.69$; **Fig 3F**). Together, these
212 data suggest that mask use is a poor predictor of COVID-19 growth at the state level.

213

214 *Mask use does not predict Summer and Fall-Winter statewide COVID-19 case totals.*

215 Greater statewide mask use could predict fewer cumulative cases during a growth wave. We tested this by
216 calculating COVID-19 case growth during Summer and Fall-Winter waves (**Fig 4A-B**). Summer wave
217 growth differed notably between Northeast and all other states; excluding the Northeast, greater
218 normalized cases on 1 Jun 2020 predicted lower Summer growth (OLS $p<0.0001$; **Fig 4C**). By contrast,
219 normalized cases on 1 October 2020 predicted Fall-Winter growth for Northeast and all other states (WLS
220 $p<0.0001$; **Fig 4D**). Excluding Northeast states, masks were not associated with lower Summer growth
221 between 1 June and 1 October 2020 (OLS $p=0.27$; **Fig 4E**). We likewise found no association between
222 mask use and Fall-Winter growth between 1 October 2020 and 1 March 2021 (OLS $p=0.93$; **Fig 4F**).
223 These data indicate that mask use does not predict Summer wave or Fall-Winter wave growth at the state
224 level and that low Summer growth in Northeast states did not predict low Fall-Winter growth. We
225 conclude that statewide SARS-CoV-2 transmission waves are independent of reported mask use [17].

226

227

228 **Discussion**

229 Our main finding is that mask mandates and use are not associated with lower SARS-CoV-2 spread
230 among US states. 80% of US states mandated masks during the COVID-19 pandemic. Mandates induced
231 greater mask compliance but did not predict lower growth rates when community spread was low
232 (minima) or high (maxima). We infer that mandates likely did not affect COVID-19 case growth [15], as
233 growth rates were similar on all days between actual or modeled issuance dates and 6 March 2021. Higher
234 mask use (rather than mandates per se) has been argued to decrease COVID-19 growth rates [11]. While
235 compliance varies by location and time, IHME estimates are robust (derived from multiple sources [17])
236 and densely sampled (day-level precision). Higher mask use did not predict lower maximum growth rates,
237 smaller surges, or less Fall-Winter growth among continental states. Mask-growth rate correlation was
238 only evident at minima. This may be an artifact of faster growth at fewer normalized cases, as well as
239 regional differences in case prevalence early in the pandemic. States in the high mask quintile grew at
240 similar rates as states in the low mask quintile after maxima (when interstate total case differences were
241 smaller than before minima). In addition, mask use did not predict normalized cases at minima, and low
242 mask growth curves trailed those of high mask (particularly Northeast) states before minima. Growth
243 maxima and Fall-Winter surges did not differ between Northeast and other states. Northeast states
244 exhibited the highest seroprevalence up to at least July 2020 [24] and constituted 80% of the top quintile
245 of mask use, which may explain their comparatively lower Summer growth. Overall, mask use appears to
246 be an intra-state lagging indicator of case growth.

247
248 There is inferential but not demonstrable evidence that masks reduce SARS-CoV-2 transmission. Animal
249 models [25], small case studies [6], and growth curves for mandate-only states [16] suggest that mask
250 efficacy increases with mask use [11]. However, we did not observe lower growth rates over a range of
251 compliance at maximum Fall-Winter growth (45-83% between South Dakota and Massachusetts during
252 maxima) [17] when growth rates were high. This complements a Danish RCT from 3 April to 2 June

253 2020, when growth rates were low, which found no association between mask use and lower COVID-19
254 rates either for all participants in the masked arm (47% strong compliance) or for strongly compliant
255 participants only [8]. Masks have generally not protected against other respiratory viruses. Higher self-
256 reported mask use protected against SARS-CoV-1 in Beijing residents [26], but RCTs found no
257 differences in PCR confirmed influenza among Hong Kong households assigned to hand hygiene with or
258 without masks (mask use 31% and 49%, respectively) [27]. Medical and cloth masks did not reduce viral
259 respiratory infections among clinicians in Vietnam [9] or China [10], and rhinovirus transmission
260 increased among universally masked Hong Kong students and teachers in 2020 compared with prior years
261 [28]. These findings are consistent with a 2020 CDC meta-analysis [29] and a 2020 Cochrane review
262 update [30].

263
264 Our study has implications for respiratory virus mitigation. Public health measures should ethically
265 promote behaviors that prevent communicable diseases. The sudden onset of COVID-19 compelled
266 adoption of mask mandates before efficacy could be evaluated. Our findings do not support the
267 hypothesis that SARS-CoV-2 transmission rates decrease with greater public mask use. As masks are
268 required in public in many US states, it is prudent to weigh potential benefits with harms. Masks may
269 promote social cohesion as rallying symbols during a pandemic [31], but risk compensation can also
270 occur [32]. Prolonged mask use (>4 hours per day) promotes facial alkalinization and inadvertently
271 encourages dehydration, which in turn can enhance barrier breakdown and bacterial infection risk [33].
272 British clinicians have reported masks to increase headaches and sweating and decrease cognitive
273 precision [34]. Survey bias notwithstanding, these sequelae are associated with medical errors [35]. By
274 obscuring nonverbal communication, masks interfere with social learning in children [36]. Likewise,
275 masks can distort verbal speech and remove visual cues to the detriment of individuals with hearing loss;
276 clear face-shields improve visual integration, but there is a corresponding loss of sound quality [37, 38].
277 Future research is necessary to better understand the risks of long-term daily mask use [30]. Conversely, it

278 is appropriate to emphasize interventions with demonstrated or probable efficacy against COVID-19 such
279 as vaccination [39] and Vitamin D repletion [40].

280
281 In summary, mask mandates and use were poor predictors of COVID-19 spread in US states. Case growth
282 was independent of mandates at low and high rates of community spread, and mask use did not predict
283 case growth during the Summer or Fall-Winter waves. Strengths of our study include using two mask
284 metrics to evaluate association with COVID-19 growth rates; measuring normalized case growth in
285 mandate and non-mandate states at comparable times to quantify the likely effect of mandates; and
286 deconvolving the effect of mask use by examining case growth in states with variable mask use. Our
287 study also has key limitations. We did not assess counties or localities, which may trend independently of
288 state averages. While dense sampling promotes convergence, IHME masking estimates are subject to
289 survey bias. We only assessed one biological quantity (confirmed and probable COVID-19 infections),
290 but the ongoing pandemic warrants assessment of other factors such as hospitalizations and mortality.
291 Future work is necessary to elucidate better predictors of COVID-19 spread. A recent study found that at
292 typical respiratory fluence rates, medical masks decrease airway deposition of 10-20 μ m SARS-CoV-2
293 particles but not 1-5 μ m SARS-CoV-2 aerosols [41]. Aerosol expulsion increases with COVID-19 disease
294 severity in non-human primates, as well as with age and BMI in humans without COVID-19 [42].
295 Aerosol treatment by enhanced ventilation and air purification could help reduce the size of COVID-19
296 outbreaks.

297

298 **Acknowledgments**

299 The authors thank Brandy Jesernik, Jay Bhattacharya, Scott Atlas, and Erik Fostvedt for manuscript input.

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430 **Figure Legends**

431 **Fig 1. Mask mandates are not associated with lower COVID-19 growth rates in continental US**

432 **States.** A. Daily COVID-19 case growth rate for continental US states from 20 April 2020 to 6 March
433 2021. Red horizontal lines denote growth rate minima (Min) and maxima (Max) after the Summer wave.
434 Surge: difference in case growth between min. and max. Thin black line and wide gray bars denote mean
435 and 95% confidence intervals, respectively. B. Early mandate states (blue) exhibited greater mask use
436 than late (green) and no (red) mandate states during the Fall-Winter wave. C. Minimum growth rates were
437 indistinguishable between early (blue) and combined late and no mandate (orange) states. D. Maximum
438 growth rates were indistinguishable among early, late, and no mandate states. E-F. Surge sizes (E) and
439 surge rates (F) were indistinguishable among early, late, and no mandate states. *: $p < 0.05$ by Šídák post-
440 test after one-way ANOVA. n.s.: not significant by Mann-Whitney U test (C) or one-way ANOVA (D-F).
441 Error bars: 95% confidence intervals.

442
443 **Fig 2. Statewide mask mandates do not predict lower post-mandate case growth in contiguous US**

444 **states.** A. Case growth was indistinguishable among states with early (blue), late (green), and no (red)
445 mandates. n.s.: not significant by one-way ANOVA. Error bars: 95% confidence intervals. B. Growth
446 curves were indistinguishable for states with early (blue), late (green), and no (red) mandates. Heavy lines
447 and shaded regions denote means and 95% confidence intervals, respectively. Post-mandate case growth
448 refers to cumulative cases between mandate issuance date and 6 March 2021 (A) or growth curves after
449 mandate issuance up to 6 March 2021 (B). For states with late and no mandates, effective dates are
450 medians of issuance dates among bordering states with early mandates.

451
452 **Fig 3. Mask use does not consistently predict COVID-19 case growth in continental US states.** A.

453 Mask use was associated with lower minimum growth rates. B. First and last mask use quintiles grew
454 from 400 to 1350 cases per 100,000 at indistinguishable rates before minima. C. Mask use was not

455 associated with maximum growth rates. D. Growth rates and normalized cases were indistinguishable
456 after maxima between first and last mask use quintiles. E. Mask use was associated with larger surge
457 sizes. F. Mask use was not associated with surge rates. A, C, E, F: Each SLR includes both Northeast
458 (solid light blue; ●) and non-Northeast (black; ●) state data. Equations are given when $p < 0.05$ for the null
459 hypothesis of zero slope. R^2 values refer to unconstrained lines of best fit.

460
461 **Fig 4. Mask use does not predict lower COVID-19 growth during the Summer or Fall-Winter**
462 **waves.** A-B. Daily COVID-19 case growth rate (A) and total COVID-19 cases (B) for US states from 20
463 April 2020 to 6 March 2021. Red vertical lines denote Summer (Jun-Oct 2020) and Fall-Winter (Oct
464 2020-Mar 2021) waves. Thin black line and wide gray bars denote mean and 95% confidence intervals,
465 respectively. C. Higher normalized cases predicted lower Summer case growth in non-Northeast states
466 (black; ●). D. Higher normalized cases predicted lower Fall-Winter case growth in Northeast (solid light
467 blue; ●) and non-Northeast (●) continental states. E. Summer case growth was independent of mask use
468 in non-Northeast states (●). F. Fall-Winter case growth was independent of mask use in Northeast (●) and
469 non-Northeast (●) continental states. C, E: SLR models exclude Northeast states (○). D, F: SLR models
470 include both Northeast and non-Northeast continental states. Equations are given when $p < 0.05$ for the
471 null hypothesis of zero slope. R^2 values refer to unconstrained lines of best fit.

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479 **Supporting Information Legends**

480 **S1 Fig. COVID-19 case growth rates in US states with statewide mask mandates issued on or before**

481 **August 2nd 2020.** Top. COVID-19 growth phases. Y-axis values are differences between the natural
482 logarithm of total cases on a day and the natural logarithm of total cases on the prior day. Thin black and
483 wide gray denote mean and 95% confidence intervals, respectively. Bottom. Individual states. Red
484 vertical lines denote dates of mask mandate issuance. Red horizontal lines indicate growth rate minima
485 (phase 4) and maxima (phase 5) after Summer waves.

486

487 **S2 Fig. COVID-19 case growth rates in US states with statewide mask mandates issued after**

488 **August 2nd 2020.** Top. COVID-19 growth phases. Y-axis values are differences between the natural
489 logarithm of total cases on a day and the natural logarithm of total cases on the prior day. Thin black and
490 wide gray denote mean and 95% confidence intervals, respectively. Bottom. Individual states. Red
491 vertical lines denote dates of mask mandate issuance. Red horizontal lines indicate growth rate minima
492 (phase 4) and maxima (phase 5) after Summer waves.

493

494 **S3 Fig. COVID-19 case growth rates in US states without statewide mask mandates.** Top. COVID-

495 19 growth phases. Y-axis values are differences between the natural logarithm of total cases on a day and
496 the natural logarithm of total cases on the prior day. Thin black and wide gray denote mean and 95%
497 confidence intervals, respectively. Bottom. Individual states. Red horizontal lines indicate growth rate
498 minima (phase 4) and maxima (phase 5) after Summer waves.

499

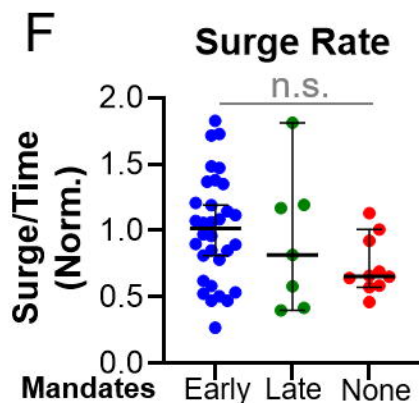
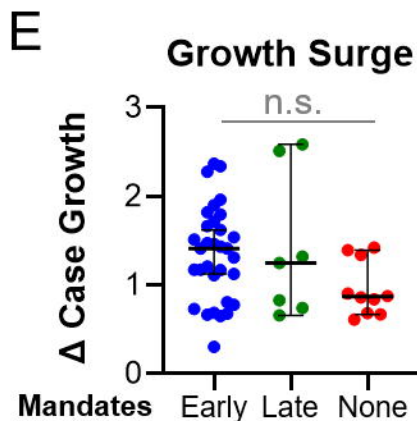
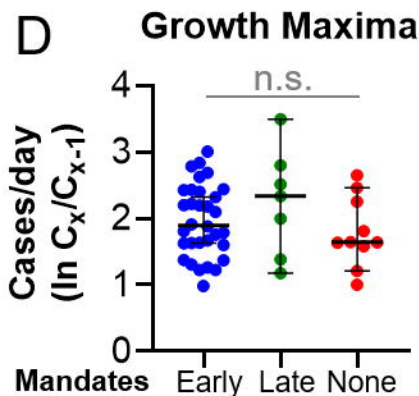
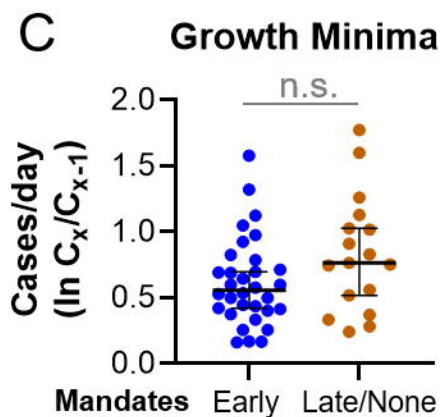
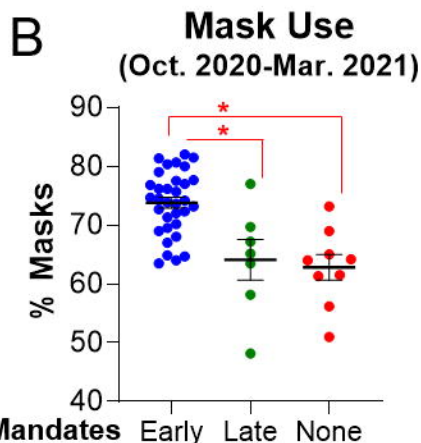
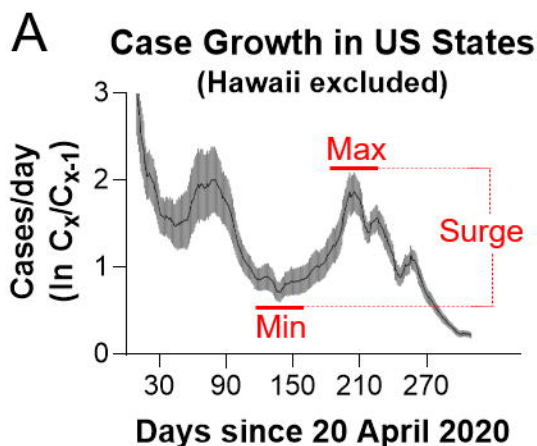
500 **S4 Fig. Total cases, growth rates, and mask use at minima in continental US states.** Left. Normalized

501 cases do not predict mask use at minima. Right. More normalized cases predict lower growth rates in non-
502 Northeast states at minima. Black circles (●): all states except Hawaii. Blue hollow circles (○): Excluded
503 Northeast states. Red squares (■): Midwest states. Green triangles (▲): Mountain-Plains States. Grey

504 triangles (▼): South states. Gold diamonds (◆): Pacific states except Hawaii. SLR models include all
505 states except Hawaii (left) or all states except Hawaii and Northeast states (right). R^2 values refer to
506 unconstrained lines of best fit.

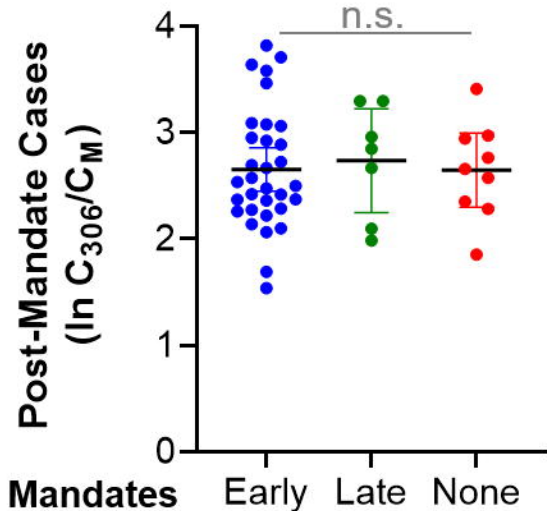
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508 **S5 Fig. Total cases, growth rates, and mask use at minima in continental US states.** Left. Normalized
509 cases do not predict mask use at maxima. Right. More normalized cases predict lower growth rates in all
510 continental states at maxima. Black circles (●): all states but Hawaii. Light blue circles (●): Northeast
511 states. Red squares (■): Midwest states. Green triangles (▲): Mountain-Plains States. Grey triangles (▼):
512 South states. Gold diamonds (◆): Pacific states but Hawaii. SLR models include all states but Hawaii. R^2
513 values refer to unconstrained lines of best fit. ϵ : Non-normal residuals (D'Agostino-Pearson $p=0.008$).

514
515 **S1 Table. Total normalized cases, daily case growth, mask use, and statistical tests.** Worksheet A.
516 Total normalized cases (cases per 100,000 residents of each US state) from 6 March 2020 to 6 March
517 2021. Total cases obtained from the CDC were divided by 2019 projected state populations and
518 multiplied by 100,000. Worksheet B. Daily case growth for each US state from 2 April 2020 to 1 March
519 2021. 7-day rolling averages are given. Red and gold text denote minima and maxima, respectively. Bold,
520 highlighted text indicate actual mandate issuance dates for early and late mandate states (yellow highlight,
521 bold red) and effective mandate issuance dates for late and no mandate states (blue highlight, bold
522 orange). Worksheet C. Mask use for each US state on specified dates or ranges of dates. Date range mask
523 use values are simple arithmetic means of daily mask use over the specified date range. Blue and red text
524 indicate states in the first and last mask use quintile, respectively (i.e., states with highest and lowest
525 mean mask use between 1 June 2020 and 1 March 2021). Mask use data are estimates provided by the
526 University of Washington Institute for Health Metrics and Evaluation. Worksheet D. Statistical test
527 summaries. Tests are reported in the order they appear in the Results. Red text specifies model
528 assumption violations, followed by alternative tests that fulfill assumptions. All reported statistics and
529 parameters were calculated with GraphPad Prism 9.1 (Prism files available upon request).



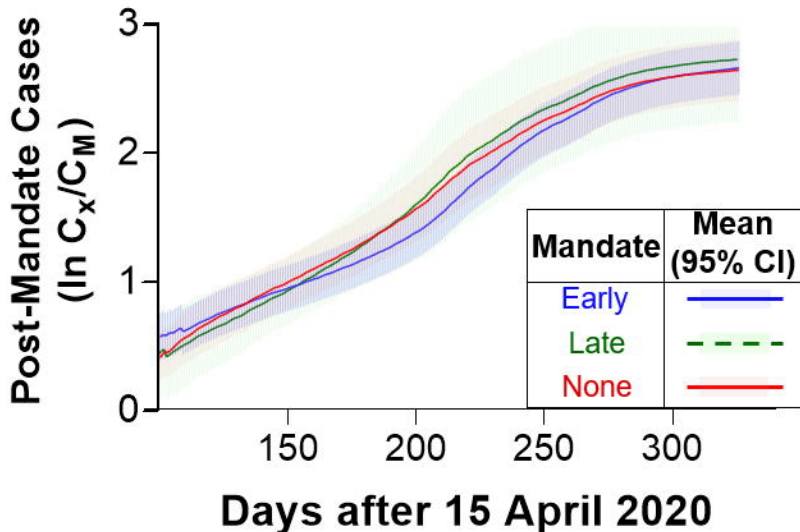
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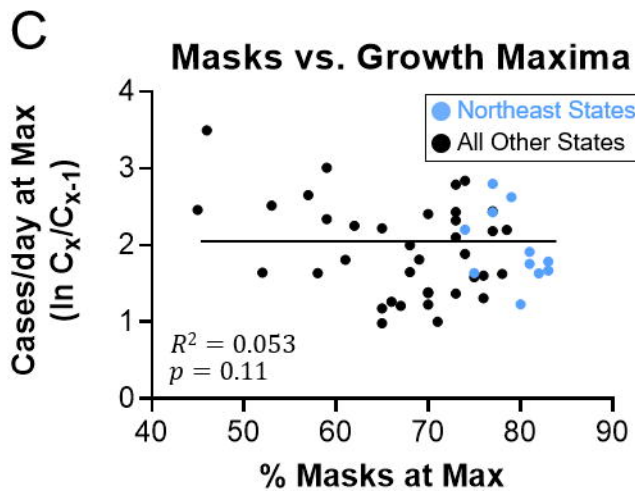
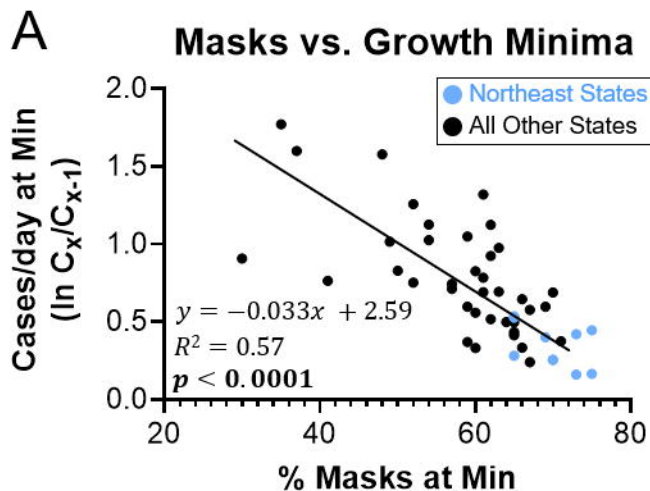
Growth After Early Mandates



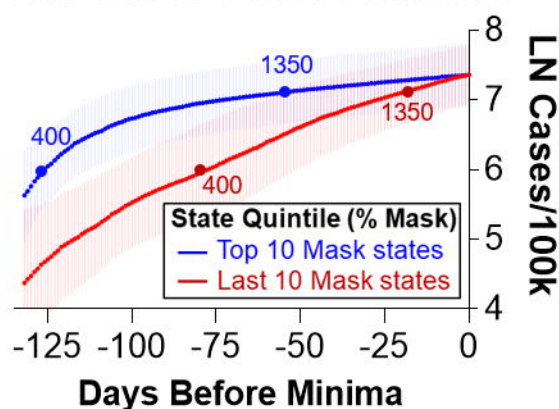
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Post-Mandate Growth Curves



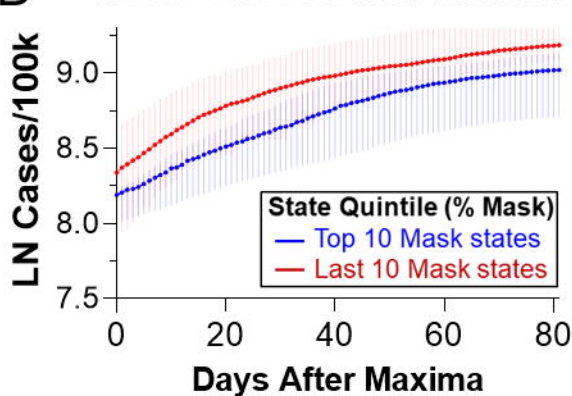


B Total Cases Before Minima

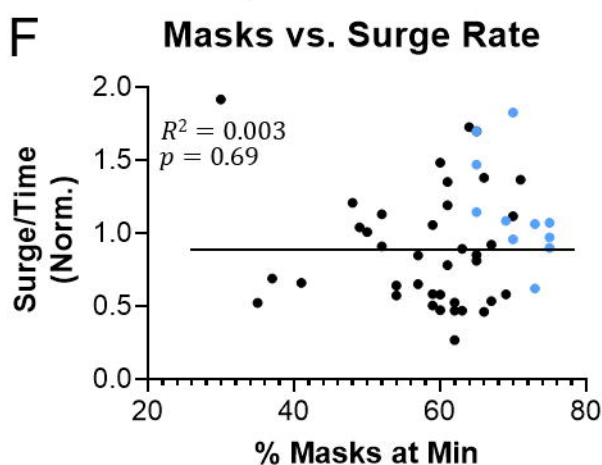
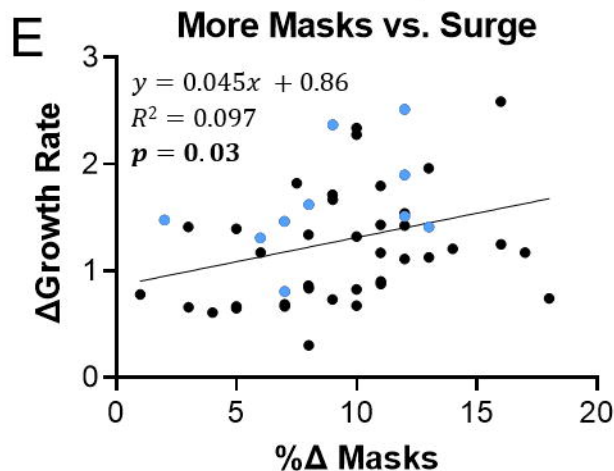


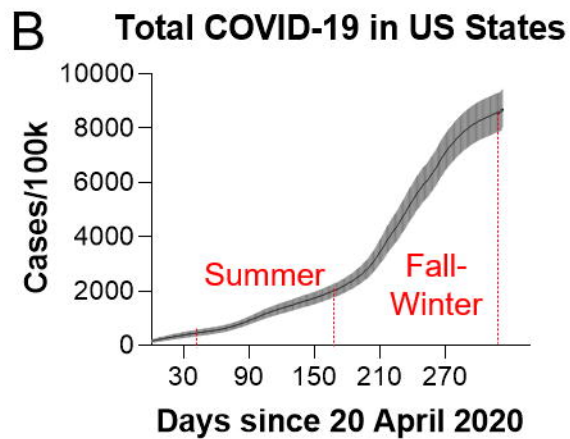
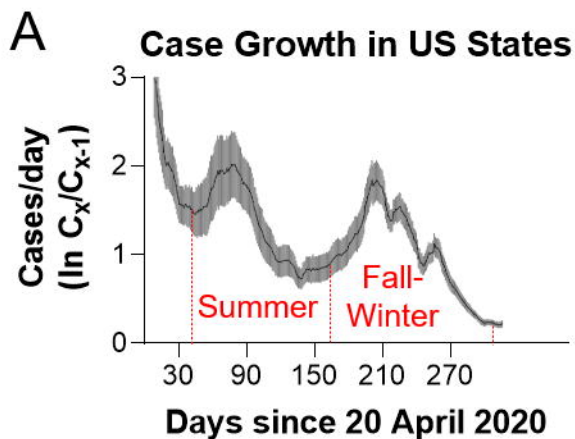
Total Cases	Mean \pm 95% CI		<i>p</i> -value
	Top 10	Last 10	
Case Growth 400-1350 cases/100k	57.7 ± 18.4	65.3 ± 16.1	0.49 (t-test)
% Masks 400-1350 cases/100k	66.3 ± 3.5	43.1 ± 4.7	<0.001 (t test)

D Total Cases After Maxima



Total Cases	Top 10	Last 10	<i>p</i> -value
Median (95% CI)			
Case Growth 0-80 days Median (95% CI)	0.88 0.82-0.95	0.87 0.66-1.2	0.85 (M-W)
% Masks 0-80 days Mean \pm 95% CI	81.8 ± 1.8	63.1 ± 4.3	<0.001 (Welch's t)





● Northeast States ○ Northeast (Excluded) ● All Other States

