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

Introduction

28

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. Respired 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

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.

3

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   $$\frac{Case\ growth}{day} = 100 * (\ln \frac{C_x}{C_{x-1}})$$

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

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

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 < α=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

5

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

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≤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 predicter 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

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

10

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 10-20µm SARS-CoV-2

293   particles but not 1-5µm 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.

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Acknowledgments

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Figure Legends

Fig 1. Mask mandates are not associated with lower COVID-19 growth rates in continental US States. A. Daily COVID-19 case growth rate for continental US states from 20 April 2020 to 6 March 2021. Red horizontal lines denote growth rate minima (Min) and maxima (Max) after the Summer wave. Surge: difference in case growth between min. and max. Thin black line and wide gray bars denote mean and 95% confidence intervals, respectively. B. Early mandate states (blue) exhibited greater mask use than late (green) and no (red) mandate states during the Fall-Winter wave. C. Minimum growth rates were indistinguishable between early (blue) and combined late and no mandate (orange) states. D. Maximum growth rates were indistinguishable among early, late, and no mandate states. E-F. Surge sizes (E) and surge rates (F) were indistinguishable among early, late, and no mandate states. *: $p < 0.05$ by Šídák post-test after one-way ANOVA. n.s.: not significant by Mann-Whitney U test (C) or one-way ANOVA (D-F). Error bars: 95% confidence intervals.

Fig 2. Statewide mask mandates do not predict lower post-mandate case growth in contiguous US states. A. Case growth was indistinguishable among states with early (blue), late (green), and no (red) mandates. n.s.: not significant by one-way ANOVA. Error bars: 95% confidence intervals. B. Growth curves were indistinguishable for states with early (blue), late (green), and no (red) mandates. Heavy lines and shaded regions denote means and 95% confidence intervals, respectively. Post-mandate case growth refers to cumulative cases between mandate issuance date and 6 March 2021 (A) or growth curves after mandate issuance up to 6 March 2021 (B). For states with late and no mandates, effective dates are medians of issuance dates among bordering states with early mandates.

Fig 3. Mask use does not consistently predict COVID-19 case growth in continental US states. A. Mask use was associated with lower minimum growth rates. B. First and last mask use quintiles grew from 400 to 1350 cases per 100,000 at indistinguishable rates before minima. C. Mask use was not

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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
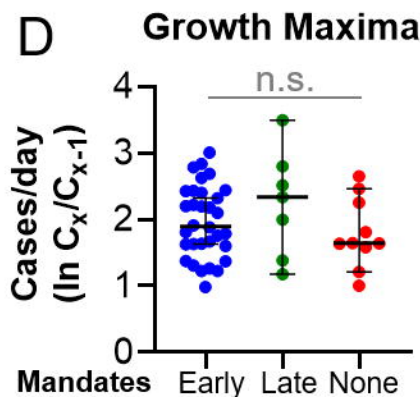
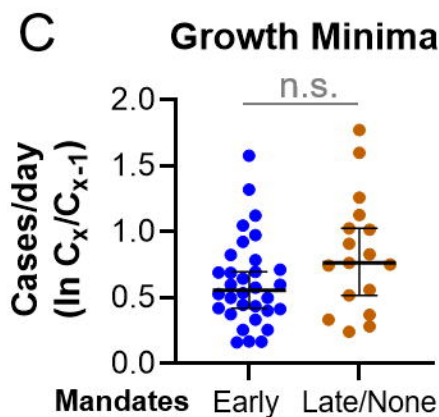485   (phase 4) and maxima (phase 5) after Summer waves.

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.
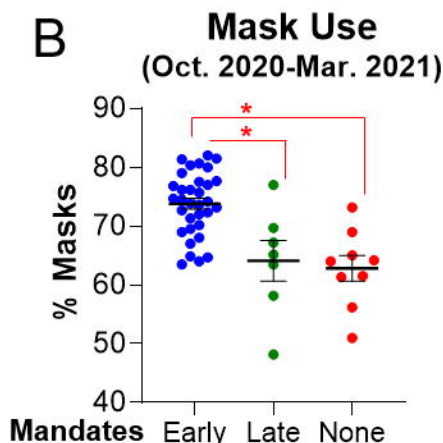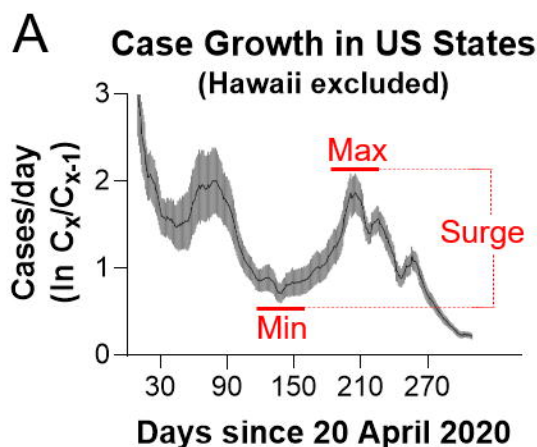
493

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

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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
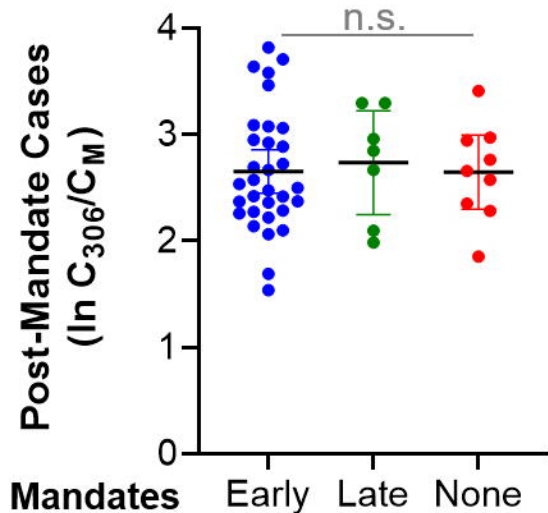
506   unconstrained lines of best fit.

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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

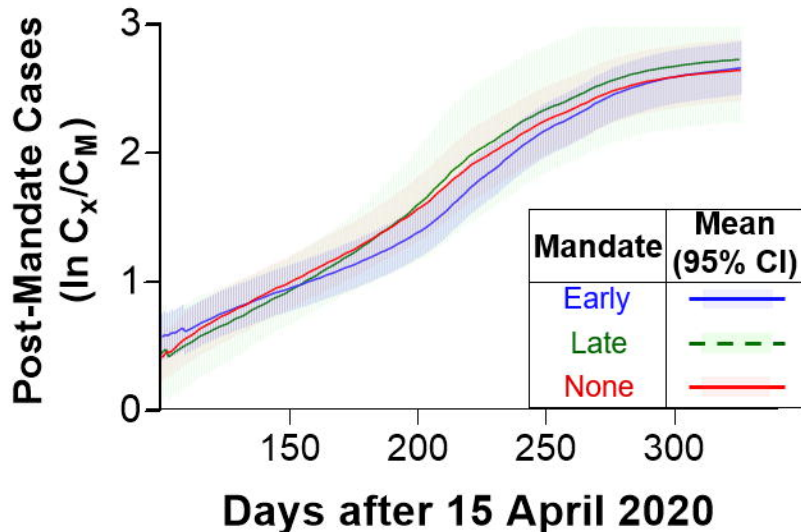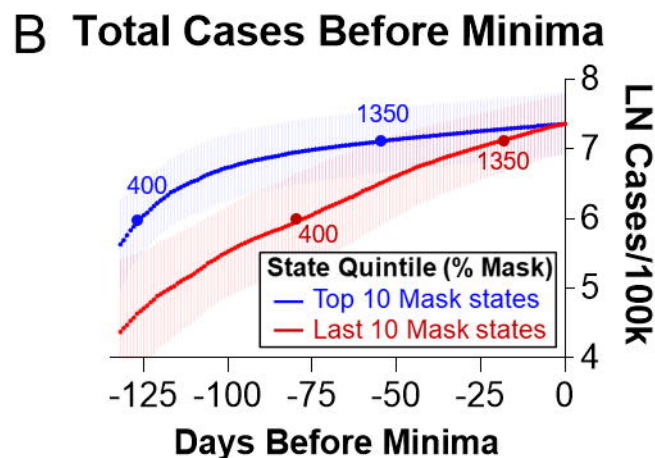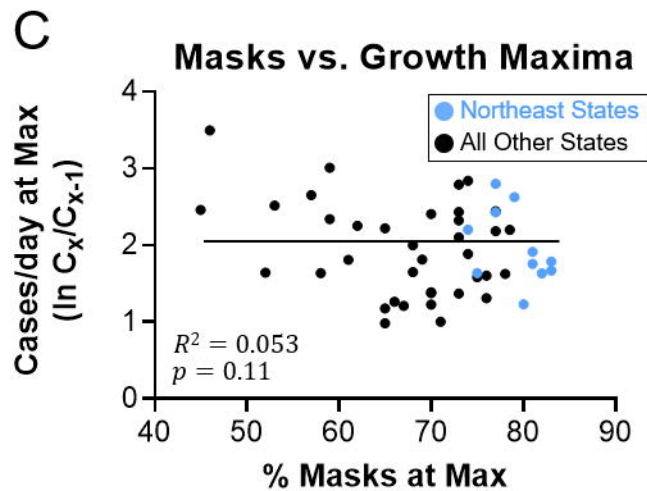529   parameters were calculated with GraphPad Prism 9.1 (Prism files available upon request).
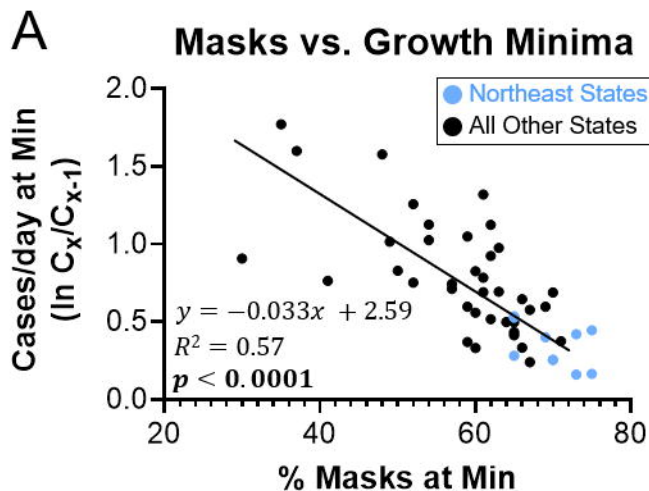
A **Case Growth in US States**
(Hawaii excluded)

Cases/day (ln C_x/C_{x-1})

Max

Surge

Min

Days since 20 April 2020

B **Mask Use**
(Oct. 2020-Mar. 2021)

% Masks

Mandates Early Late None

C **Growth Minima**

Cases/day (ln C_x/C_{x-1})

n.s.

Mandates Early Late/None

D **Growth Maxima**

Cases/day (ln C_x/C_{x-1})

n.s.

Mandates Early Late None

E **Growth Surge**

Δ Case Growth

n.s.

Mandates Early Late None

F **Surge Rate**

Surge/Time (Norm.)

n.s.

Mandates Early Late None

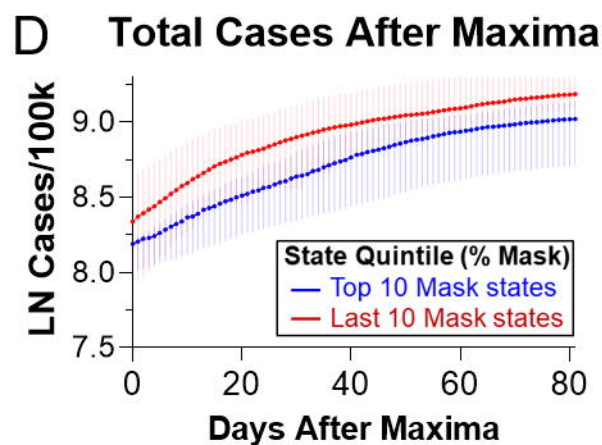**A** Growth After Early Mandates

Post-Mandate Cases ($\ln C_{306}/C_M$)

n.s.

Mandates: Early, Late, None

B Post-Mandate Growth Curves

Post-Mandate Cases ($\ln C_x/C_M$)

Days after 15 April 2020

Mandate	Mean (95% CI)
Early	
Late	
None	

A Masks vs. Growth Minima

$y = -0.033x + 2.59$
$R^2 = 0.57$
$p < 0.0001$

C Masks vs. Growth Maxima

$R^2 = 0.053$
$p = 0.11$

B Total Cases Before Minima

Total Cases	Top 10	Last 10	p-value
Mean ± 95% CI			
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 Median (95% CI)	Top 10	Last 10	p-value
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 ± 95% CI	81.8 ± 1.8	63.1 ± 4.3	<0.001 (Welch's t)

E More Masks vs. Surge

$y = 0.045x + 0.86$
$R^2 = 0.097$
$p = 0.03$

F Masks vs. Surge Rate

$R^2 = 0.003$
$p = 0.69$

A Case Growth in US States

Cases/day (ln C_x/C_{x-1})

Summer   Fall-Winter

Days since 20 April 2020
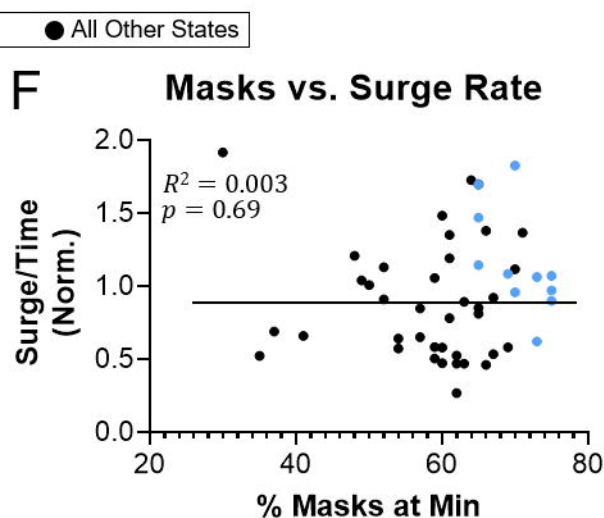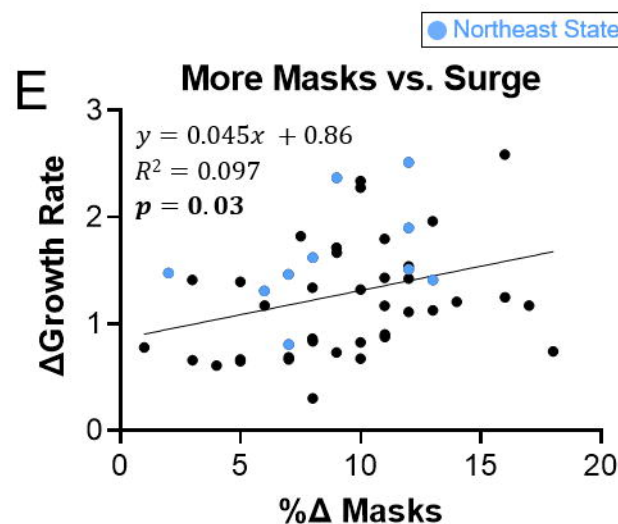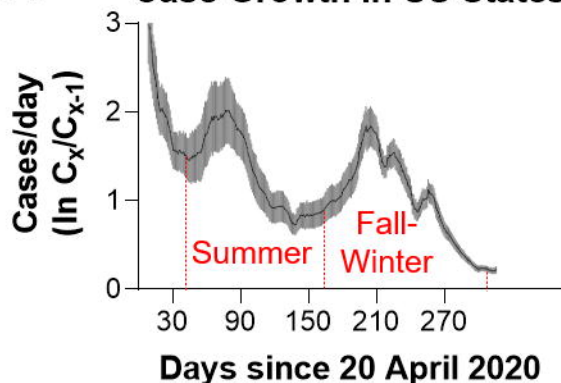
B Total COVID-19 in US States

Cases/100k

Summer   Fall-Winter

Days since 20 April 2020
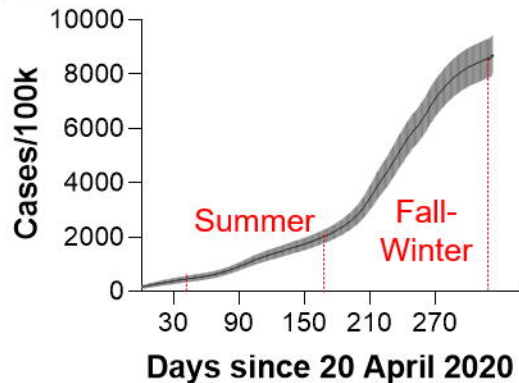
● Northeast States   ○ Northeast (Excluded)   ● All Other States

C 1 Jun Cases vs. 1 Jun-1 Oct Growth

Summer Cases (ln C_{1001}/C_{601})

$y = -0.002x + 2.71$
$R^2 = 0.61$
$p < 0.0001$

Cases per 100k (1 Jun 2020)
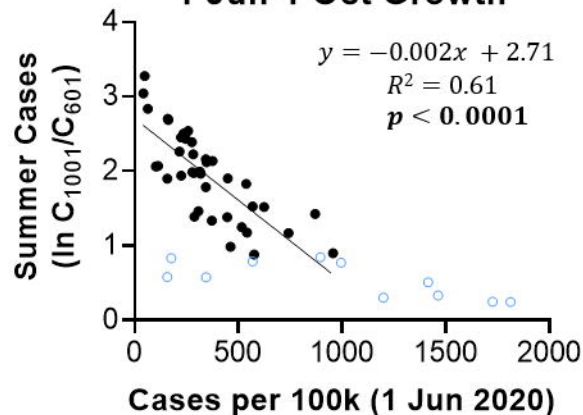
D 1 Oct Cases vs. 1 Oct-1 Mar Growth

Fall-Winter Cases (ln C_{301}/C_{1001})

$y = -0.00032x + 2.2$
$R^2 = 0.73$
$p < 0.0001$

Cases per 100k (1 Oct 2020)

E Masks vs. Growth (Summer)

Summer Cases (ln C_{1001}/C_{601})

$R^2 = 0.033$
$p = 0.27$
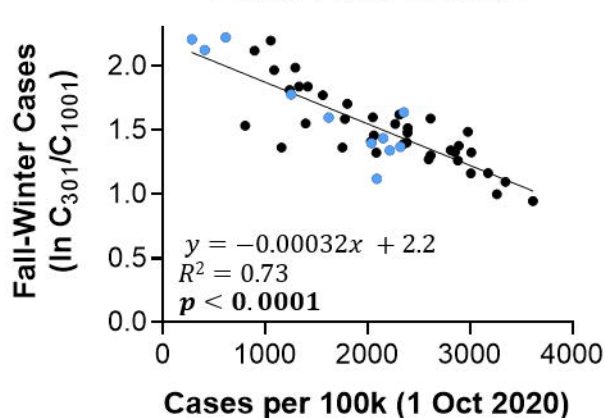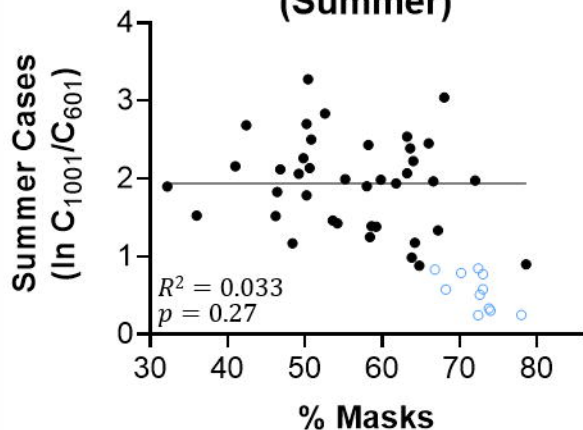
% Masks

F Masks vs. Growth (Fall-Winter)

Fall-Winter Cases (ln C_{301}/C_{1001})

$R^2 = 0.0002$
$p = 0.92$

% Masks