Review of Non-pharmaceutical Interventions on Transmission Reduction for COVID-19

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Introduction:

The goal of this report was to research how specific strategies, typically referred to as non-pharmaceutical interventions (NPIs), have been used to reduce transmission and thus, inform policy decisions. We searched for peer reviewed publications from January, 2020 through June, 2020 that sought to calculate quantitative reductions in virus transmission due to NPIs, measured as changes in the effective reproductive number (R_t). We also utilized reports quantifying growth rate changes by converting them into R_t values. The NPIs included in this report are shelter-in-place orders (SIPOs), venue or business closures, wearing cloth facial coverings, bans on mass gatherings, school closures, and travel restrictions.

Key Points:

This report summarizes existing research on the impact of NPIs in reducing COVID-19 transmission. Larger reductions in transmission can be achieved through SIPOs. Smaller reductions in transmission may be achievable through closures of nonessential businesses, masking mandates, bans on mass gatherings, or school closures. It is likely that combinations of different NPIs may be needed to reduce transmission enough to “flatten the curve” or reduce R_t to less than 1.

Non-pharmaceutical Intervention	Range of Effects	Number of Peer-Reviewed Publications
Shelter-in-Place Orders:		
Adjusted	18.7% (8.7% - 28.3) reduction in R_t	1
Unadjusted	21.7% - 81% reduction in R_t	3
Nonessential Business/Venue Closures	13% (3.2% - 22.8%) reduction in R_t	1
Cloth Face Coverings	4% - 26% reduction in R_t	3
Mass Gathering Bans	0% - 3% reduction in R_t	2
School closures	0% - 15% reduction in R_t	3
Travel Restrictions	70.4% - 77% reduction in case exportations	3

Shelter-in-Place Orders:

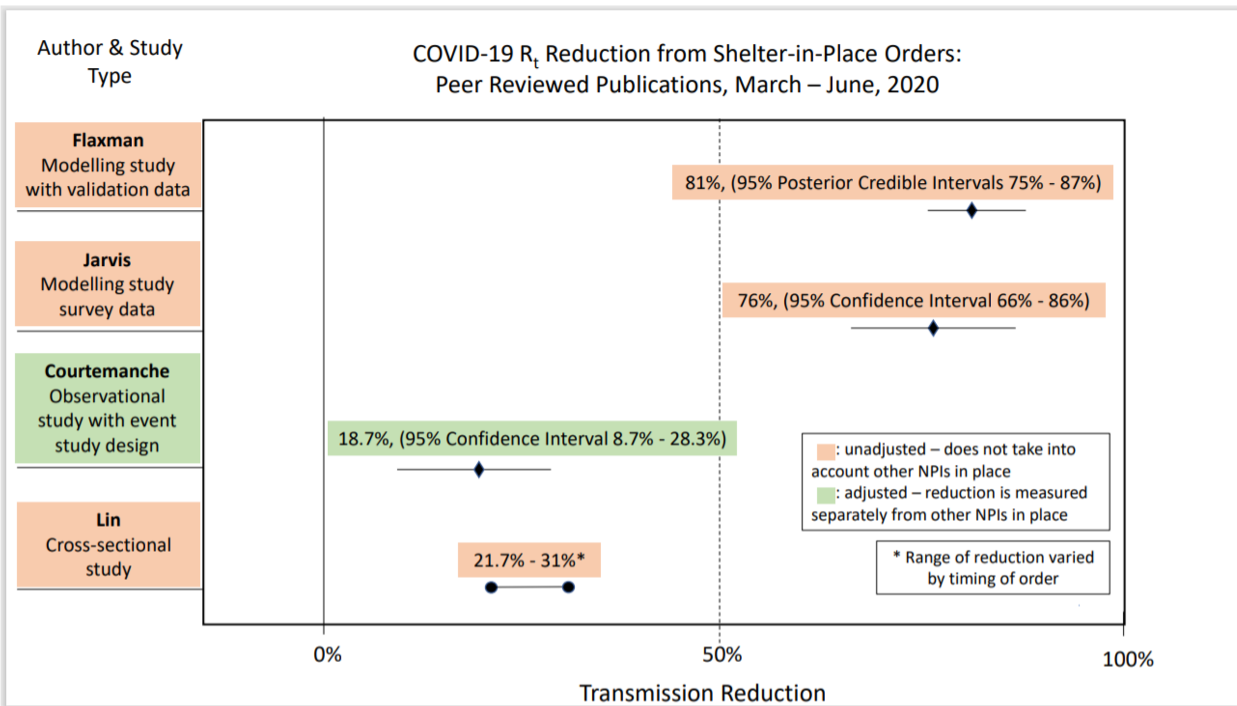
Four publications met criteria for evaluation shelter-in-place orders (SIPOs). SIPOs are also termed “stay-at-home orders” or “lockdowns” in the publications below. Regardless of the term used, the definition in the articles below all include an order to stay home, except for essential household shopping or work and thus include closures of schools and nonessential businesses (including restaurants, bars and entertainment venues).

1) A report from the Imperial College (Flaxman et al., published in June) used early epidemic outbreaks in Europe to estimate effectiveness of various governmental NPIs to lower R_t (1). According to the authors’ model, based on 11 European countries, lockdowns accounted for a reduction in R_t 81% with posterior credible intervals including 75% - 87% reductions (1). The model used deaths as a proxy for confirmed cases to account for different testing rates and strategies. Although the researchers were clear that the lockdowns had a dramatic effect on transmission reduction, many of the other NPIs were implemented at similar times, which limited their ability to disentangle the impact of those other individual NPIs. Data for this analysis was from the beginning of the COVID-19 outbreak up until May 4th, 2020.

2) An article by Courtemanche et al., examined the impact of NPIs in the U.S. at the county level. They included all U.S. counties (3138 counties). The authors controlled for population density, education, political orientation and age. Data for this study was from March 1st through to April 27th. They calculated reduction of epidemic growth in time intervals of days past since the SIPO was implemented: 6-10 days, 11-15 days, 16-20 days and 21+ days. The reduction in epidemic growth point estimates were: 3%, 4.5%, 5.9%, 8.6%, over those time blocks, respectively (2). These reductions were converted to reduction percentages in R_t (3), for up to a 18.7% reduction in R_t, with 95% confidence intervals from 8.7% - 28.3%.

3) Jarvis et al., conducted a survey study in the U.K. that analyzed daily contacts before and after a lockdown was ordered on March 23rd. This study measured a 74% reduction in contacts per person and through the researchers’ calculations, this level of reduction in contacts could lower R_t from 2.6 to 0.62 (4). This drop in R_t represents a 76% reduction in transmission. The researchers plan to continue to evaluate the repeated surveys of this nature for 16 weeks and will thus be able to measure adherence to a lockdown after more time has gone by as well as changes in contact patterns. They carefully selected survey participants to represent the general U.K. population by location, age, gender, and socioeconomic status.

4) Lin, et al. conducted a study of shelter-in-place orders (SIPOs) in the U.S. and grouped locations into county level data and then further categorized locations based on whether the order was an "early" or "late" order. Early orders were those in place by March 23rd and late orders were in place by April 7th. Nine states implemented early orders, 34 states had late orders and 8 states had no orders. They followed growth rate patterns based on case data from the New York Times and calculated decrease in epidemic growth. Counties in the 9 states with early orders experienced a reduction in growth of 31% whereas late order counties showed a 21.7% reduction in growth (5). Even counties in states that did not have SIPOs showed a reduction of 13% and the authors speculated this may have been due to spillover effects from other counties as well as national advisories. We converted the authors' report of growth rates into R_t values (3).



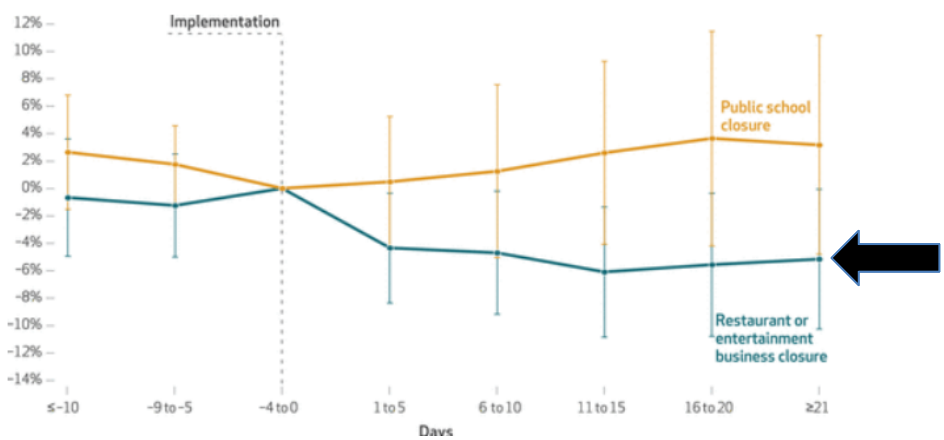
Courtemanche reported adjusted reductions, or those above and beyond other NPIs in place, where Flaxman, Jarvis, and Lin simply measure reductions and do not separate out effects of other NPIs already in place.

Venue/Nonessential Business Closures:

Only one published article addressed venue/business closures as an NPI. This NPI addressed closures of restaurant dining rooms, bars, entertainment centers, and gyms.

1) Courtemanche et al., (introduced above) found a statistically significant reduction in epidemic growth through simultaneous closures of nonessential businesses and venues (2). They found reductions in growth rates between 4.4 - 6.1 percentage points depending on the time lapse since implementation (see graph). We converted (3) growth rate reductions into R_t values for a 13% reduction in R_t with 95% confidence intervals at 3.2% - 22.8%.

Exhibit 3 Estimated effects of public school closures and restaurant or entertainment center closures on the daily growth rate in confirmed COVID-19 cases in the US, 2020



See turquoise line. Courtemanche showed how closures of restaurants, gyms, bars and entertainment centers could lower epidemic growth by up to 6% over time, up to 21+ days after implementation. This reduction in growth rates can be translated to a 13% reduction in R_t.

A modeling study by Delen et al., supports evidence that closures of highly public places such as restaurants and bars contributed to the lowering of transmission in 26 European countries. While this study did not calculate actual reduction in transmission, they used mobility data from February 28th to April 17th and combined this data with case data from the European Centre for Disease Prevention and Control and were able to model that reductions in mobility to these highly public places likely contributed more to reducing disease transmission than other less public places such as residential areas and some work places (6).

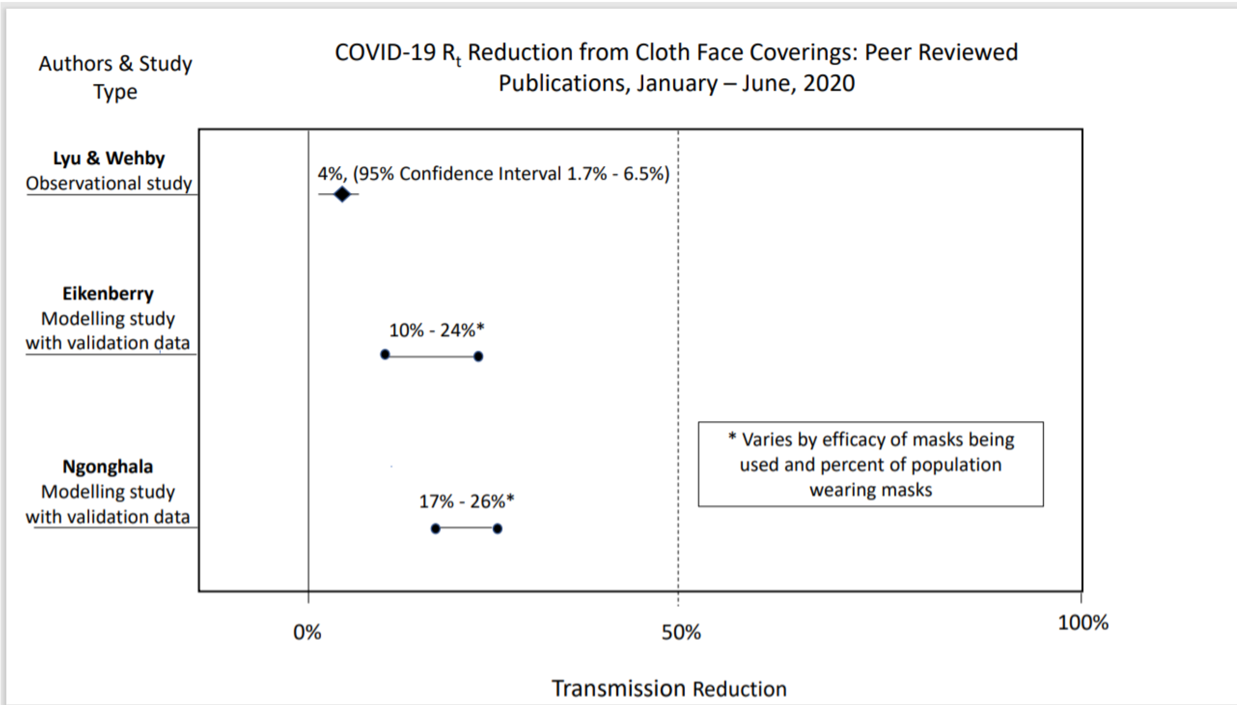
Cloth Face Coverings:

Three published articles met the criteria for inclusion into the masks/face covering NPI section. We were looking for data about reduction in COVID-19 transmission from homemade face coverings because any use of masks by the general public will likely not involve the widespread use of medical-grade masks.

1) Eikenberry et al., estimated that if 80% of people had worn masks in New York state and Washington state between March 1st through April 2nd (New York) and February 20th to April 2nd (Washington), mortality could have been reduced (7). They looked at reductions in mortality from masks that are 20%, 50%, and 80% effective to help account for different kinds of masks, from homemade coverings to medical-grade masks. They also modeled different percentages of a population using masks, and like other research, concluded that the larger the proportion of a population using masks, the more effective this NPI could be at reducing transmission. For 20% efficacy masks, they estimated that the reduction in infectious contact rate could be between 10% and 24% (this range reflects the difference between 50% or 80% of a population wearing these masks). Infectious contact rate is a proportional measurement to R_t values. The data for model calibration was from John's Hopkins University from January 22nd through April 2nd and the data for validation from New York and Washington was from March 1st through April 2nd and February 20th to April 2nd, respectively.

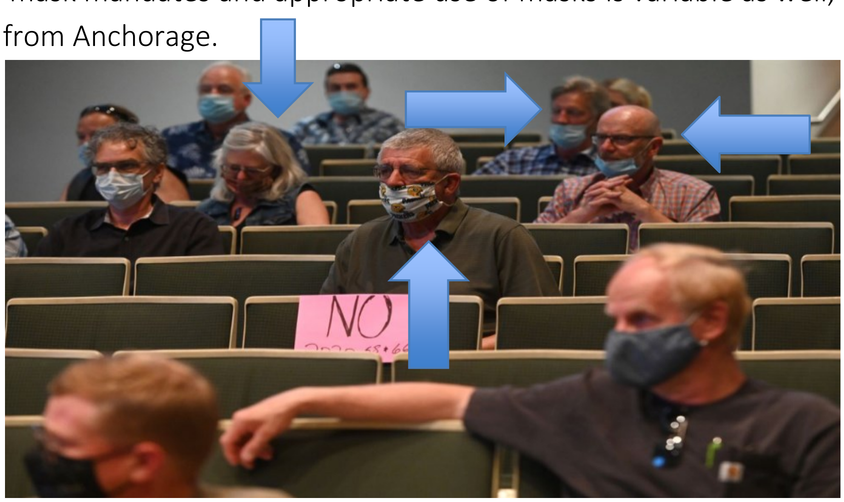
2) Ngonghala et al., used similar techniques and found similar results, looking at reduction in R_t as the quantitative outcome. The authors used data from New York state as well as the entire U.S. to calibrate their model. They modeled a 26% reduction in R_t with 80% of people wearing 30% effective masks and the level of transmission reduction decreased to 17% when only 50% of people wear the same 30% effective masks (8). Data to calibrate their model was from March 1st through April 7th.

3) Lyu & Wehby used policies around the U.S. from 15 states that implemented masking mandates to measure their effect through a "natural experiment". This research focused on cloth face coverings, as all mandates emphasized preserving medical masks for healthcare workers. Mandates also encouraged the continuation of social distancing and they controlled for population densities, socioeconomic and demographic factors as well as other mitigation interventions in place (9). Their results were presented in time blocks after implementation and as reduction in growth rates. The policies they examined were implemented from April 8th to May 15th and they evaluated effects from March 31st to May 22nd. We converted their reduction in growth rates to reductions in R_t for a reduction of 4% with 95% confidence intervals of 1.7%-6.5% (3).



Eikenberry & Ngonghala provide a range of transmission reduction effects depending on efficacy of mask and the percentage of the population wearing them. The ranges of values here show effects of the lowest efficacy masks, best representing homemade cloth face coverings. Eikenberry's range reflects 20% effective masks and 50%-80% compliance. Ngonghala's range reflects 30% effective masks at 50%-80% compliance. Lyu and Wehby measured a statistically significant reduction in growth rate that we converted to a 4% reduction in R_t after 21+ days of policy implementation.

The rationale for using modelled ranges of very low efficacy masks is because data on homemade masks has shown they can be effective at filtering viral particles under controlled conditions of experiments (10–12). However, this data generally reports that homemade masks are less efficacious than medical grade masks and does not extend to less controlled settings. Adherence to mask mandates and appropriate use of masks is variable as well, as evidenced by a recent photo from Anchorage.

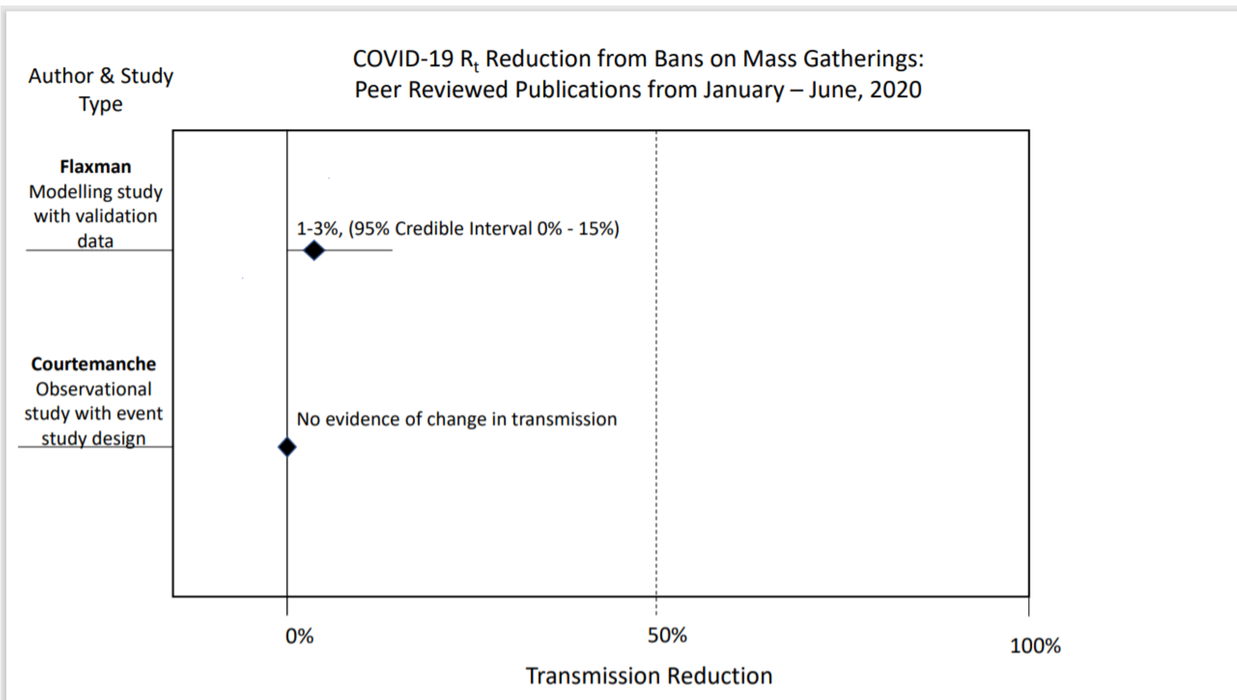


Mass Gathering Bans:

Two publications met the criteria for this NPI. Mass gatherings were defined by Flaxman et al., as gatherings of 100 or more people and Courtemanche, et al. described that most of the bans in the U.S. that they analyzed prohibited 50 or more people from gathering.

1) Flaxman et al., (introduced above) examined bans on mass gatherings as well. They examined public events, so may not have included private mass gatherings. This NPI resulted in a 1-3% reduction of R_t, with 95% credible intervals including results up to about a 15% reduction (1).

2) Courtemanche et al., found that bans on mass gatherings did not statistically (p>0.56) change growth rates of cases (2). Their confidence intervals did include some very modest reductions, so could not rule out completely that the bans had a small effect in reducing transmission.



Flaxman measured reduction in R_t while, Courtemanche reported that bans on mass gatherings did not reduce transmission.

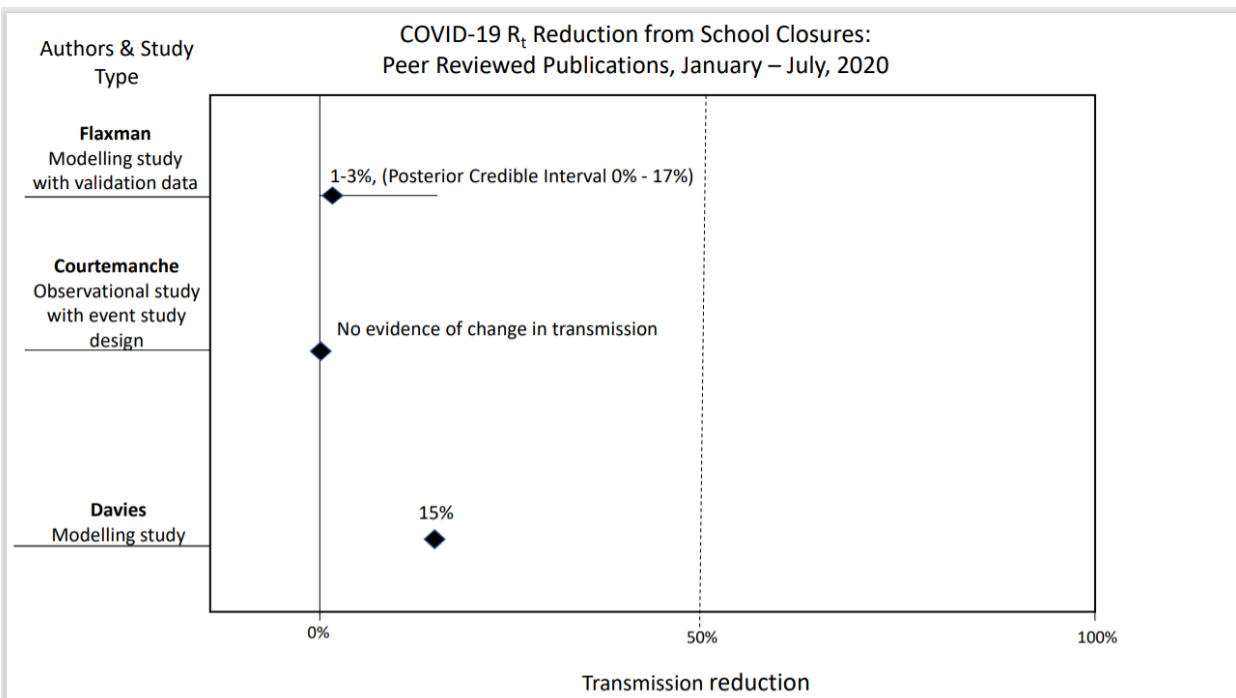
School Closures:

Three papers met the criteria and addressed school closures. These articles address public schools, both primary and secondary, although Flaxman clarifies that Sweden did not close its primary schools (and is included in his 11-country analysis).

1) Flaxman et al., showed a 1-3% relative reduction in R_t for school closures, depending on whether the intervention was the first or followed others (1). Credible intervals included an effect up to a 17% reduction.

2) Courtemanche et al., found no significant reduction in epidemic growth due to school closures. They hypothesized that person-to-person interactions were replaced with out-of-school interactions as closures of schools came before shelter-in-place orders (2).

3) A modelling study by Davies et al., used data from the UK from December, 2019 to March, 2020 concluded that school closures would not have as large of an impact on reduction in transmission as other NPIs, but may reduce the R_t by 15%, if implemented near the peak of an unmitigated epidemic (13). It may be prudent to consider the effect would be different if an epidemic wasn't at its peak and other NPIs were already be in place.



Flaxman and Davies both measured reductions in R_t while Courtemanche reported no significant reduction in growth rates from school closures.

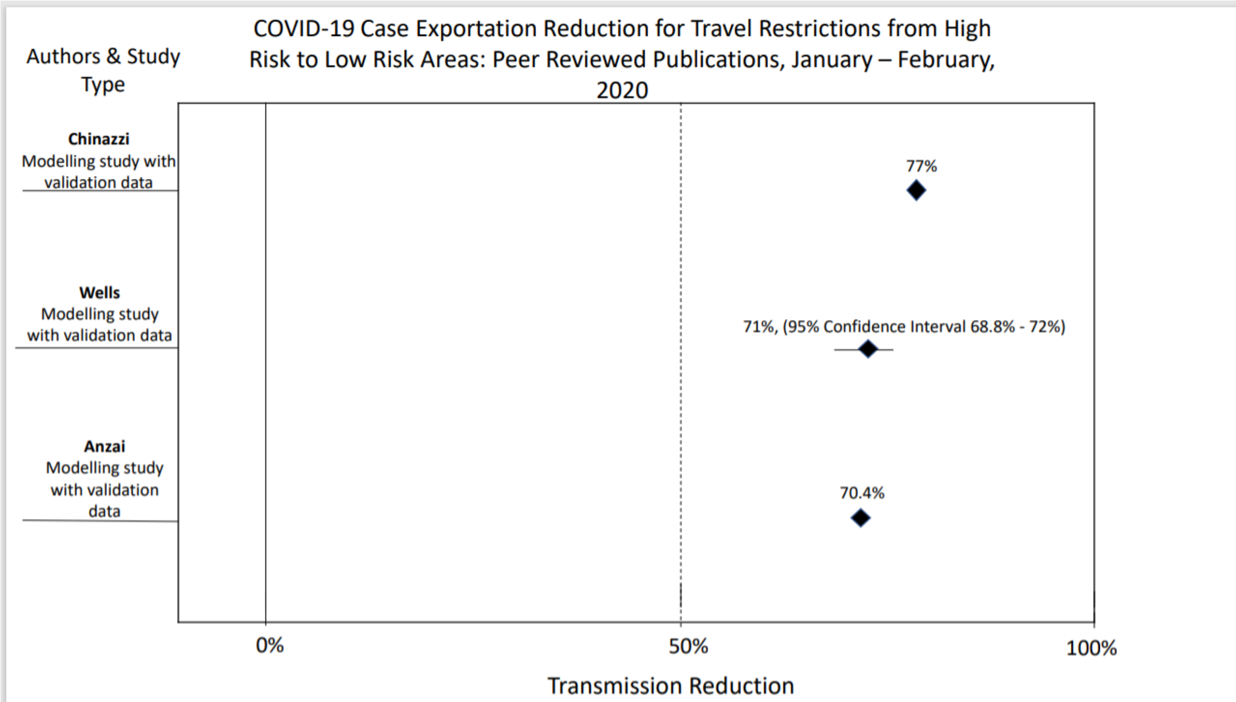
Travel Restrictions:

Three articles met the criteria for inclusion in travel bans. It is important to understand that the travel restrictions being analyzed here are those stipulating bans on outward travel from areas with high rates of community transmission to locations with no or very few cases. In Alaska, the only applicable use of this NPI would be in protecting rural Alaska by banning travel into those communities, as most urban communities have evidence of significant community transmission. Furthermore, some rural communities are now reporting more cases and showing evidence of community spread.

1) An article by Chinazzi et al., found a 77% relative risk reduction in case importations from Wuhan, China to other countries due to travel bans (14). This study also showed that inter-city travel bans only slowed transmission to other parts of China and were less effective at overall reduction in transmission because cities outside of Wuhan had already been seeded with cases when the ban was put into place. While travel restrictions can be a useful tool, they are less effective when cases have already spread beyond the area where travel is restricted. Data used in the researcher's model was from January 22nd through to mid-February. China put a complete travel ban in place on the 23rd of January.

2) Wells et al., found that 71% of potentially exported cases were averted due to international travel restrictions (15). Their data was also from January to mid-February. This study looked at incidence data for COVID along with global airport network connectivity to analyze the risk of case exportation to other countries. They used Monte Carlo simulations to estimate that 64% of exported cases were pre-symptomatic and thus airport screening with thermometers is likely not very effective. The reduced rate of case exportation was 81% with this model and the averted cases was 71%. The conclusions from this article are that early travel restrictions are helpful to prevent exportation, but contact tracing in both the epicenter and in newly exported cases as well as voluntary quarantine are complementary measures that are also very important containment and mitigation steps.

3) Anzai et al., found a 70.4% reduction in potentially exported cases from China to other countries due to travel restrictions (16). Data for this study was from January 28th to February 7th. The researchers looked at the impact of drastic reduction in travel out of China to Japan and modelled this data for use in other locations. The key takeaway was that the travel restrictions averted 226 cases for a 70% reduction in exportation.



*Graph shows the percentage of reduction in exported cases from high transmission areas to low or no transmission areas. The only applicable use of this in Alaska at this point is in protecting rural Alaska. Chinazzi measured averted cases outside of China after Wuhan and the Hubei province shut down travel on January 23rd. Wells also measures the percentage of cases averted outside of China. Anzai measured the percentage of cases reduced via importation to Japan and modelled that for other locations. Because travel restrictions were all measured in the same way, we did not attempt to convert these values.

Limitations:

Finding quantitative results from the implementation of NPIs has proved challenging, since many NPIs were put into place at the same time. In addition, some of the findings in this report may be enhanced, or reduced as more evidence is available. For example, the finding that bans on mass gatherings didn't produce larger reductions in transmission may have been in part due to limited data, because we have seen these events contribute to transmission in clubs in South Korea or during a choir practice in the U.S (17,18). In fact, new research that has not yet been peer reviewed points towards larger reductions in transmission from school and university closures and incrementally larger reductions in transmission through incrementally more stringent restrictions on the size of gathering bans (19). Consequently, based on additional evidence, gatherings and venues should be considered as a potential transmission risk, particularly when considered within the context of the type and location of a gathering or venue (20). Additionally, in a personal communication (August, 2020) with S. Jeon, Ph.D., CDC Health Economics and Modeling Unit, it was noted that the researchers working on the Courtemanche et al., study had stressed that the timing and backdrop of NPIs in place were likely to affect the outcomes of individual interventions. For instance, schools were generally closed prior to other NPIs and SIPOs were put into place after most others were in place. Utilized in a different order, results may vary greatly.

Methods:

We conducted a literature search through PubMed. Search terms are below:

PubMed database:

1) ("Coronavirus" [MeSH] OR "Coronavirus Infections" [MeSH] OR "Betacoronavirus" [MeSH] OR "Coronavirus" [TIAB] OR "COVID-19" [Supplementary Concept] OR "COVID-19" [TIAB] OR "severe acute respiratory syndrome coronavirus 2" [Supplementary Concept] OR "SARS-CoV-2" [TIAB] OR "coronavirus disease 2019" [TIAB]) AND:
    a) ("Public Health Surveillance" [Mesh] OR "public health intervention" [TIAB] OR "nonpharmaceutical intervention" [TIAB] OR "non-pharmaceutical intervention" [TIAB]).
    b) ("mass gatherings"[TIAB]) OR ("mass gatherings" [MeSH])
    c) ("school closures"[TIAB]) OR ("school closures" [MeSH])
    d) ("face-masks" [TIAB]) OR ("face-masks" [MeSH]) OR ("face-coverings" [TIAB]) OR ("cloth face-coverings" [TIAB]) OR ("masks" [TIAB]) NOT ("N95"[TIAB]) NOT ("N95"[MeSH])
    e) ("travel restrictions" [TIAB]) OR ("travel restrictions" [MeSH])
    f) ("nonessential business closures"[TIAB]) OR ("venue closure"[TIAB]) OR ("restaurant closures"[TIAB]) OR ("bar closures"[TIAB]) OR ("nonessential business closures"[MeSH]) OR ("venue closure"[MeSH]) OR ("restaurant closures"[MeSH]) OR ("bar closures"[MeSH])

g) (“shelter-in-place” OR “lockdown” OR “stay-at-home orders” AND “COVID-19 mitigation”)

We excluded articles that were not peer-reviewed. Searches were done from mid-June through mid-July. In addition, articles were sent out informally by workgroup members that had not been identified through official search methods. These articles were reviewed by team members for appropriate methods. A total of 546 articles were identified and 11 are included in this analysis.

Data from articles that reported changes in growth rates were converted into R_0 values so a side-by-side comparison of data could be appreciated. We utilized a linear formula useful for emerging infections where details of transmissibility may be limited (3). The generation time utilized for this conversion was based on a middle value of those reported (21,22) of 5 days. The formula then was:

$$R_t = 1 + rT_c,$$

where r = growth rate and T_c = mean generation time

Growth rates were taken from the respective studies and when not made available, national data on growth rates from the Courtemanche et al., was used. We attempted to make conservative choices for our assumptions in order not to overstate effects on R_t values or reductions. Because of these conversions and assumptions about the conditions in the formula, estimations of reductions in R_t should be interpreted with caution.

An example of how the formula was used to convert growth rate data from Lin et al., is below. The 31% decrease in R_t value corresponds to the high range (early SIPO order) for this study in the graph on page 3.

1. Original growth rate of 21.48% is converted to R_t: 1 + (0.2148 x 5) = 2.07
2. Reduction in growth rate, 12.8% is subtracted from original growth rate: 21.48 - 12.8 = 8.68%
3. Then this reduced growth rate is converted to R_t: 1 + (0.0868 x 5) = 1.43
4. Percent decrease in R_t values is then calculated: 2.07 – 1.43 = 0.64, then 0.64 ÷ 2.07 = 0.309 (31%)

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