Methods/Results

Methods

Population

We present a spatial explicit stochastic agent based model that recreates the day to day dynamics in a typical nursery home during the COVID pandemic in the United States. We use an hourly time step resolution and we ran the model for 150 days.

Population structure

We used the floor plans and satellite imagery to recreate the spatial structure of a typical nursery home in the US (figure 1). The nursery home consist on 58 bedrooms designated for the residents, recreation areas (such as dining room, and activities rooms), and rooms for staff use. In the initial conditions there are 3 residents per room (total 174) and 170 staff divided into 3 different turns. The decision on the population distribution was based on information obtained from an interview with a nursery home in California.

Population dynamics

In our simulation, an agent can interact with other agents based on its location. Given the current guidelines of recommendations for long term care facilities, there are no visitations and the residents spend most of the day in their rooms, so they can only interact with their roommates and the staff. In our model each resident will have at least one interaction with the staff per day which is based on different contact rates depending on the staff type (CN, RN, LPN), The staff will have different contact rates that were parametrized according on the average number of resident contacts in a normal day (REFERENCE: Table shared via email??). The contact rates are presented in table from supplementary materials.

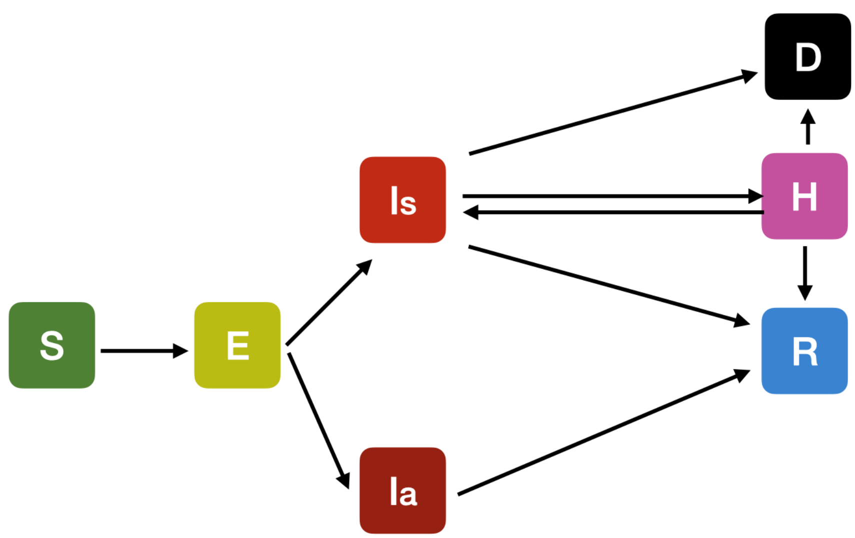
The staff agents are assigned to one of 3 different work schedules (morning, afternoon or night) and they spend 8 hours inside the nursery home and the rest of the time outside in the community. We only follow the agents inside the nursery home and when the agents are outside we assume that they all have the same probability of contacting other people.

Disease dynamics:

The transmission between agents inside the facility will depend on two parts, which are the probability that a person will shed the virus and the probability that another person will get the virus. We decided on model the transmission this way to represent scenarios where the infected and susceptible could have different combination of interventions (i.e. only infected received the intervention, only susceptible received the intervention, both received the intervention, etc..). The parametrization of the transmission parameters was based on observed outbreaks in nursery homes in California.

The introduction from the community to the facility depends on a parameter *Introduction_p* that represents how likely is that a staff agent will be infected in the community.

All the agents start as susceptible and after 1 day there is a resident introduced with the disease. Then we follow up for 150 days or until the disease has been absent for more than 14 simulation days. Once the transmission between a infectious agent to a susceptible agent has been successful, the susceptible agent becomes exposed and based on a distribution for the latent period λ, the agent becomes infectious after λ number of days, which can be either symptomatic and asymptomatic. The agent can infect other agents only when its in the Infectious state, then they remain infectious during 15 days and they transition to recovered. The agents can transition to infectious to hospitalized at any moment based on the hospitalization rate. When the agents has been recovered they acquire infection immunity, which lasts for 120 days.



Transmission parameters:

Name	Value	Reference
Latent period (λ)	$Lognormal(7, 3)$	(He et al. 2020)[b,c]
Shedding probability	0.4	[a]
Infection probability	0.4	[a]
Introduction probability	0.01	[a]
Asymptomatic probability	0.25	[a]
Infection duration	15 *days*	
Hospitalization rate	0.11	

[a]Explored for sensitivity analysis and scenario modeling, [b]truncated distribution between a boundary of reasonable values, [c]fitted to a distribution

Interventions

We explore 3 different COVID-19 control strategies and the combination of them. Each of the interventions have an impact in the transmission of the disease, interventions such as the use of PPE and vaccination reduces the probability of transmission affecting directly the *Shedding* and *Infection probability*, while the isolation affects the transmission indirectly stopping the agent to interact with other agents. The equation 1 shows the effect of *PPE effect* and *Vaccine effect* on the transmission probability, where $odds_\omega$ represent the global transmission probability for all agents, OR_γ represent the odds ratio for the *PPE effect*, and $OR\pi$ is the *Vaccine effect*. This probability is computed for all agents at each step so we can have different probabilities of transmission based on the interventions each individual received.

$$p_T = \frac{e^{\ln(odds_\omega)+\ln(OR_\pi)+\ln(OR_\upsilon)}}{1 + e^{\ln(odds_\omega)+\ln(OR_\pi)+\ln(OR_\upsilon)}}$$

For the implementation of the vaccination, we specified by the proportion of residents and staff vaccinated, and a fixed interval between the first and second dose. Then the vaccination immunity will have a decay of 120 days and the individual will no longer have the vaccination immunity protective effect.

Since there is still some uncertainty in the effect of the use of PPE and the vaccine for older population, we started with values that are within the range of reported values and then varied these values for the sensitivity analysis and scenario modeling.

Testing and isolation

Our model represents the testing of the population with 2 different approaches:

- Passive, individuals are tested once that they present symptoms, this approach is focused on the early detection of symptomatic individuals.
- Active, a proportion of individuals are tested with a given frequency. In baseline scenario, 1 resident per room and all the staff are tested weekly. If 1 of the residents in a room is detected positive, the rest of the residents in that room are also tested.

Once a individual has been detected positive is isolated. There are special isolation rooms for the residents and in the case of the staff they are sent home. Once the individual is tested negative it return to the facility.

Interventions parameters:

Name	Value	Reference
Test detection probability	75%	[a]
Proportion of Staff tested	90%	[a]
Proportion of Residents tested	33.3	[a]
Frequency of testing	Weekly	[a]
PPE Effect (OR_π)	0.34089	(Chu et al. 2020)[a]
Vaccine effect first and second dose (OR_υ)	60%,90%	(Pfizer-BioNTech 2020)[a]
Vaccine immunity duration	120 *days*	[a]

[a]Explored for sensitivity analysis and scenario modeling, [b]truncated distribution between a boundary of reasonable values, [c]fitted to a distribution

Scenario modeling

To asses the effect of different combination of interventions we defined different scenarios. As December 2020, the vaccination has not been implemented yet in neither the residents or staff.

- Baseline Scenario S00: The baseline scenario follows the current interventions implemented in a typical nursery home. Testing is performed once a week to all the staff and one resident per room. Once that the resident is detected positive is sent to a isolation room, and in the case that one of the staff members test positive, it will be send home. Both the staff and residents are required to use PPE.

- Scenario S01: This scenario focus on improving the testing capacity, Instead of testing the staff and residents weekly, they are tested every 3 days.

- Scenario S02: This scenario also explores the improvement of the testing capacity, but instead of increasing the frequency of testing, it increases the proportion of residents tested from 1/3 to testing all the residents weekly.

- Scenario S03: This scenario focus on the vaccination. The vaccine is distributed equally among residents and the staff.
- Scenario 04: In this scenario the staff is prioritized over the residents for vaccination.

Scenarios based on the different efficacy reported by the papers (Baden et al. 2020) and (Polack et al. 2020) - Vaccine is equally effective for both residents and staff (Polack et al. 2020).
- Vaccine is less effective in older population using Pfizer data - Vaccine is less effective in older using Moderna data

Scenario	T_f	T_r	T_s	V_e	V_d	V_r	V_s
S00	Weekly	33.3%	100%	NA	NA	0	0
S01	2 days	33.3%	100%	NA	NA	0	0
S02	Weekly	100%	100%	NA	NA	0	0
S03	Weekly	33.3%	100%	85%	120 days	60	60
S04	Weekly	33.3%	100%	85%	120 days	20	100

T_f Frequency of testing, T_r Residents tested, T_s Staff tested, V_e Vaccination efficacy, V_r Residents vaccinated, V_s Staff vaccinated

Results

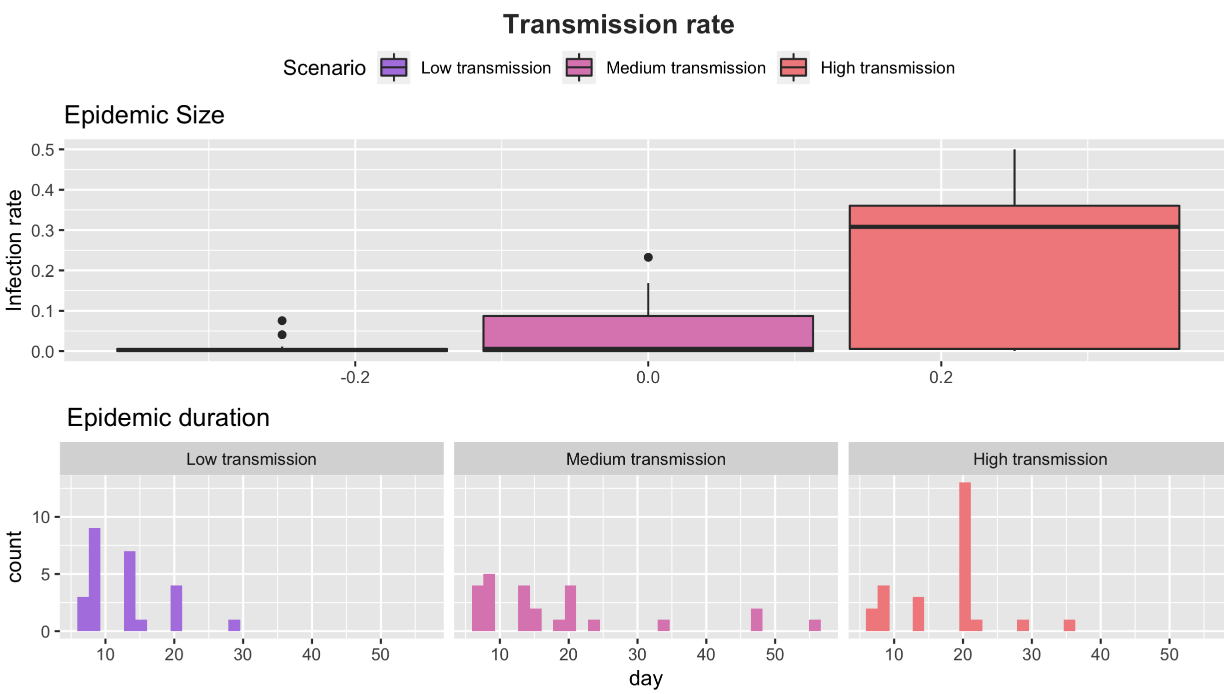
Sensitivty analisis

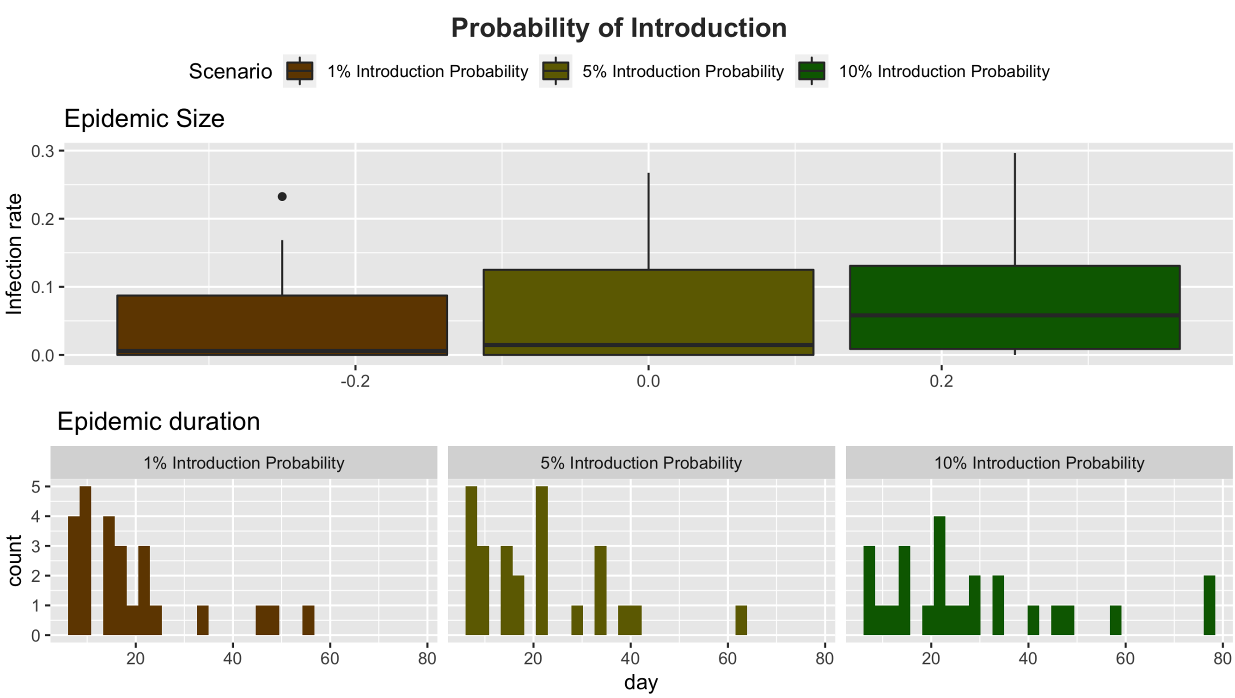
We performed sensitivity analysis on some parameters to explore the influence on the outbreak size and duration.

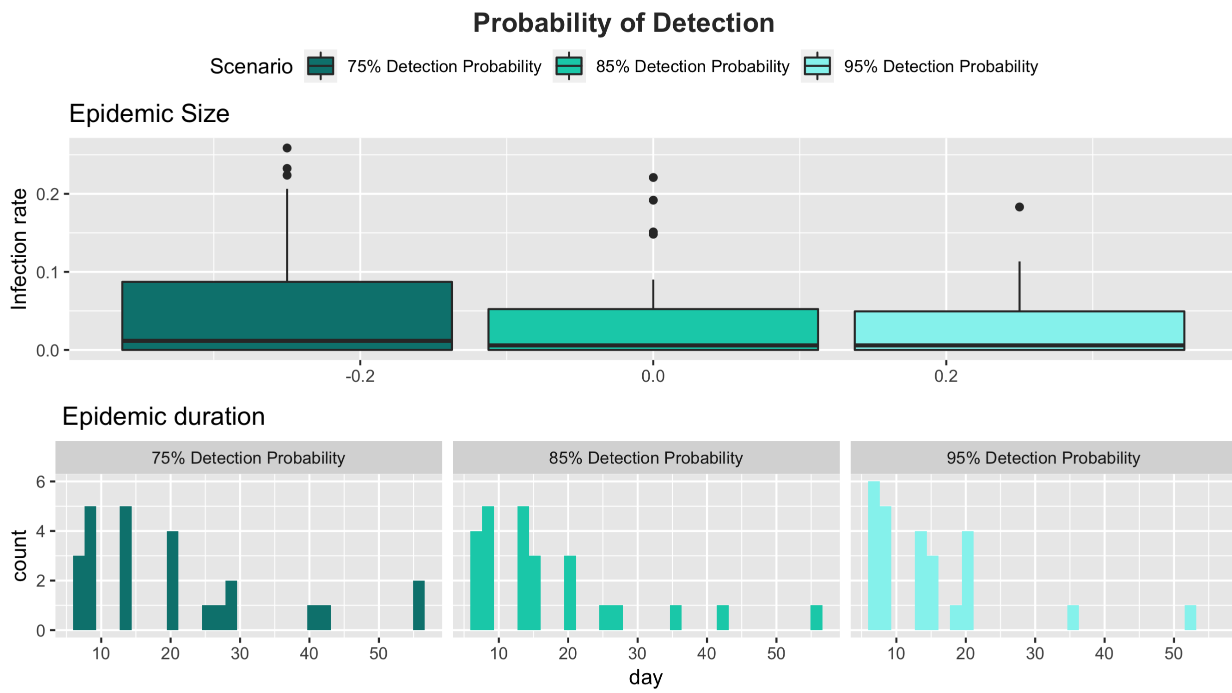
- Disease Parameters:
  - Transmission probability (for both shedding and infection)
  - Introduction probability (low risk, medium risk, high risk)

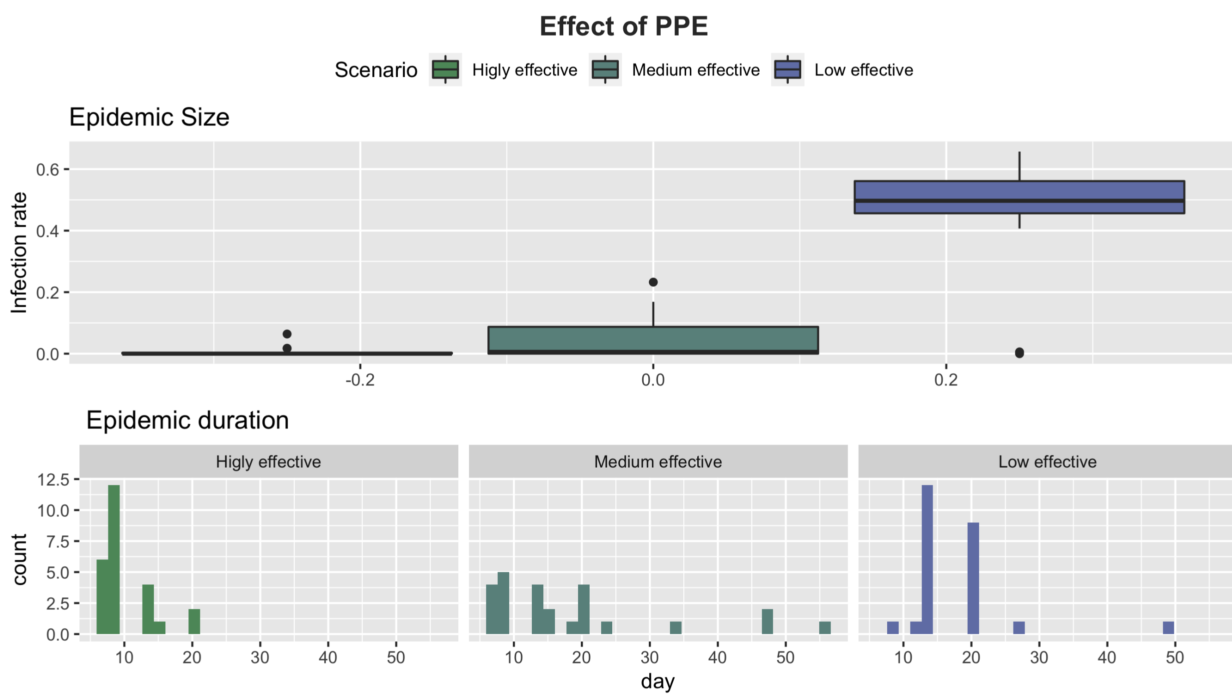
- Interventions
  - Frequency of testing (1 week, 5 days, 3 days)
  - Detection probability

- PPE effect
- Vaccine effect
- Vaccine immunity decay









Scenario modeling

- Strategic vaccination, focus on staff
- Testing every 2 weeks
- Testing every week
- Is there a vaccination threshold

What happens if the vaccine is not as effective in older population? How can we distribute the vaccine more effective? should we focus on staff? When we focus on staff we block the staff resident transmission

balance between testing and vaccination. Who should get more tests?

|Scenario|

References

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