Vaccination and herd immunity

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Project: The importance of vaccination

Some people cannot be vaccinated. This concerns, for example, young babies, pregnant women, or people whose immune systems are severely compromised. A weakened immune system can be due to diseases such as cancer but also to immuno-suppressive drug treatment (after organ transplantation, for instance, people need to take medication that suppresses their immune responses such that their body does not reject the foreign organ). The immune systems of immuno-compromised people may not respond to the vaccine, meaning that they will not gain immunity. Second, while the risk of complications is very low in healthy people, life vaccines (e.g. the measles vaccine) can be very dangerous to people with a weakened (or not yet fully developed) immune system. At the same time, the people who cannot be vaccinated are often the ones for whom the disease is most dangerous.

While the people themselves cannot be vaccinated, the healthy people in their surroundings can be. By doing so, they protect the unvaccinated from infectious diseases as well. This is called *herd immunity*. Let us look at this phenomenon more closely.

Material and preparation

In this project, you will simulate a measles virus spreading in a population of individuals, some of whom are vaccinated while others are not. Initially, two people are infected with measles. They have contracted the disease outside of the community we are looking at. You will look at three different populations of 100 individuals, each with a different number of vaccinated individuals: 0, 50, and 95.
You will need:

- red, blue, and white paper[1]
- a piece of green paper
- scissors
- small box or other container

Cut about 100 paper squares of each colour (tip: you can print a 10x10 table in Excel and cut the cells). These squares represent healthy but unvaccinated (white), vaccinated (blue), and infected (red) individuals. Using these squares, you will create different populations for the different experiments. Cut two more squares from the green paper—these represent individuals who cannot be vaccinated due to one of the reasons listed above and for whom the disease is particularly risky ("high-risk individuals").

[1] Of course, you can use different colours.

Simulation steps

Read the steps of the simulation below carefully. You will follow them to simulate 3 different populations (A-C).

1. **Let's mix:** 4 individuals go to a party, another 4 to a shopping mall, another 4 to a restaurant...and to many other places. Close your eyes and pick 40 squares from the box, and place them in **10 different piles of 4 squares each**. These ten piles represent different groups of people coming into contact close enough to spread the disease, if any of them is infectious.
2. **Infection:** Now look at the piles. If any of the piles contain an infected individual, all the other unvaccinated individuals in the group are infected with measles: replace all the white squares in this pile by red ones. Vaccinated individuals (blue squares) are not infected (if there are any—in Simulation A, there are no vaccinated individuals).
3. Are there any susceptible individuals (green squares) in the infected pile? If yes, mark this event in the table and replace them with red ones.
4. **Counting:** Count the number of infected and healthy individuals and write these numbers into the corresponding tables below.
5. Place all 100 squares back into the container (make sure they are of the correct colour—some of them are new, some old). Shake thoroughly.
6. Repeat steps 1-5 six times to simulate the spread of the disease over time, and use your data to fill in corresponding tables.

Before you start the simulations, write a clear and testable hypothesis for how the number of vaccinated individuals affects the spread of the disease.

A. No one is vaccinated.

In the first simulation, no one is vaccinated. Take 96 white squares (unvaccinated individuals), 2 red squares (individuals with measles), and 2 green squares (high-risk individuals) and shake them thoroughly in a small container. Follow the steps described in "Simulation steps" above, and fill in Table 1.

Time point	0	1	2	3	4	5	6
Infected	2						
Healthy	98						
High-risk individuals affected [y/n]							

Table 1: *Spread of measles in an unvaccinated population.*

B. 50 % of the population is vaccinated

In the second simulation, only 50 % of individuals are vaccinated. Take 46 white squares (unvaccinated individuals), 50 blue squares (vaccinated individuals), 2 red squares (individuals with measles), and 2 green squares (high-risk individuals) and shake them thoroughly in a small container. Follow the steps described in "Simulation steps" above and fill in Table 2.

Time point	0	1	2	3	4	5	6
Infected	2						
Healthy	98						
High-risk individuals affected [y/n]							

Table 2: *Spread of measles in a partially vaccinated population.*

C. 95 % of the population is vaccinated

In the last simulation, almost everyone, except very few individuals, is vaccinated. Take 1 white square (unvaccinated individual), 95 blue squares (vaccinated individuals), 2 red squares (individuals with the measles), and 2 green squares (high-risk individuals) and shake them thoroughly in a small container. Follow the steps described in "Simulation steps" above and fill in Table 3.

Time point	0	1	2	3	4	5	6
Infected	2						
Healthy	98						
High-risk individuals affected [y/n]							

Table 3: *Spread of measles in a partially vaccinated population.*

Analysis

1. Make a graph (or three different graphs) showing the changes in the numbers of healthy and sick individuals in time in all simulated populations.
2. What do you observe? In a few short sentences, summarise the most important results of the simulations.
3. What happened with the high-risk individuals in your simulations? Were they affected in all four scenarios?
4. If not, why not? If yes, when?
5. Compare your hypothesis and your results. Do your results confirm or contradict your hypothesis? Explain.
6. What do you think would happen if more people went out every time?
7. In order to achieve herd immunity, doctors recommend vaccinating 90 to 95 percent of the population. Why is the percentage so high?
8. You only ran the simulation once for each scenario. Is this enough to make scientific conclusions?
9. Go to `web.evolbio.mpg.de/evoltheo_corona/HU_Vaccination/index_eng.php`. We have prepared a computer simulation for you, that runs the same simulations as you just did by hand. It runs 1000 times and gives you the average numbers. Play with the number of vaccinated individuals. What do you observe? Are the results consistent with the results of your simulation? If not, can you explain?

Project checklist

Your completed project report should include:

- your hypothesis,
- filled-in tables and graphs,
- a photo of your experiment, and
- your responses to the questions in the Analysis section.