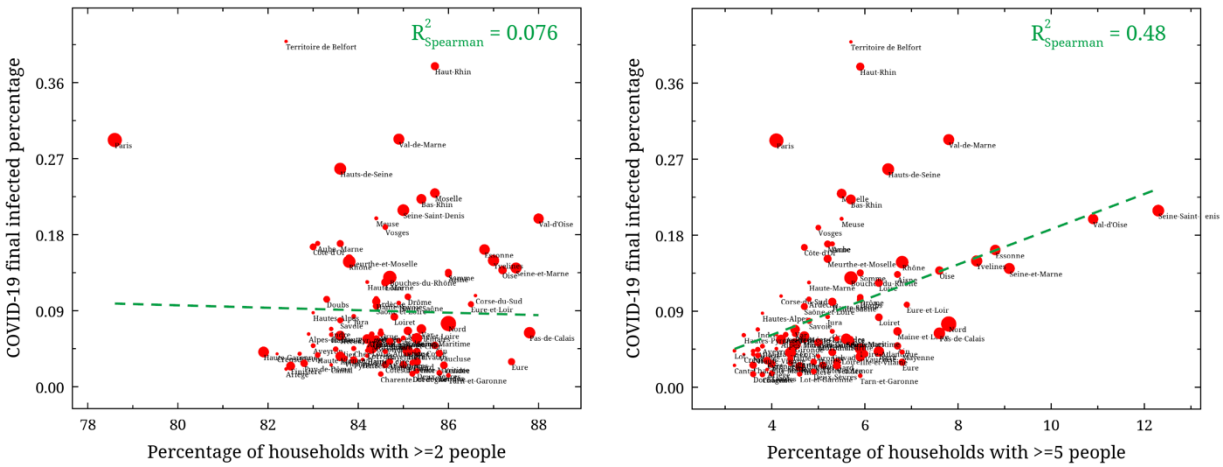
Strategy testing: impact of random testing and targeted testing on infection rates

Currently, Norwegian authorities are aiming for a strategy of "strong repression", maintaining the reproductive number *R* of the disease below 1. Effectively, this is equivalent to the prevalence of the disease declining over time. Recent reports from FHI indicate that this objective is currently being fulfilled. However, current measures involve a substantial restriction on daily life and incur a high social and economic cost. It is therefore of great interest to investigate which and to what degree restrictions can be lifted without *R* exceeding 1.

Testing for infection allows us to identify individuals for which there is an absolute need for isolation. This is especially important as many cases are asymptomatic or mildly symptomatic while being infective, and these cases may therefore spread (relatively) freely. Ideally, exhaustive and accurate high-frequency testing of the entire population would allow for selective strict quarantine of infected individuals, while healthy individuals could continue to lead unrestricted lives. However, in reality testing capacity is currently limited and reserved for certain groups. As testing capacity increases, it may become possible to set aside a certain portion of the testing capacity for the general population. However even with such an allowance, it may be difficult to test as many as one would ideally want. It is therefore of utmost important to identify how to get the most beneficial effects from the testing - that is, identify an approach to testing that confers the largest reduction in *R* for a given number of tests.

In devising a testing strategy, we let the following considerations and data serve as guides:

- Within-household spread is difficult to affect through policy, as most measures imposed by authorities affect the public sphere.
- Even in cases where COVID-19 are identified and where individuals most probably will isolate themselves independently of governmental guidelines, isolation from one's own household is often infeasible due to close living quarters or the need to attend to young children. These constraints are accentuated for large families.
- Empirical data from France suggest that there is a relationship between household size and final level of infected people in a region. This is illustrated in the two following plots, where each circle represents a county and the size of a circle reflects population of the county. In the left panel, when all households with two or more people are included, there is no discernible relation between household size and final level of infection. When limiting the household size to 5 or more people (right panel), there is a noticeable relation to measured



infection level. Interestingly, infection rates seem to correlate better with the proportion of large households than with the average household size (data not shown).

In line with common sense, and supported by the above data from France, our computational simulation results show that larger households are:

- more likely to get infected, as there are more individuals through which the disease can enter the household;
- more susceptible to in-household spread, as there are more individuals to pass the disease onto within the household. In a two-person household, one only needs to avoid infection by the other if they bring the disease into the household. In a five-person household, avoiding infection not only involves not getting infected by the first case, but also by any other household members that first household member might infect;
- more likely to pass the disease on, as there are more possibilities for the infection to move on into general society.

In terms of strategy, this suggests:

- If within-household spread for infected households is inevitable, measures should focus on preventing export of the disease from these households into society at large;
- Since infection of one household member strongly increases the risk of infection of another, entire households should be viewed as a unit for epidemic purposes;
- Large households define a particular risk group.

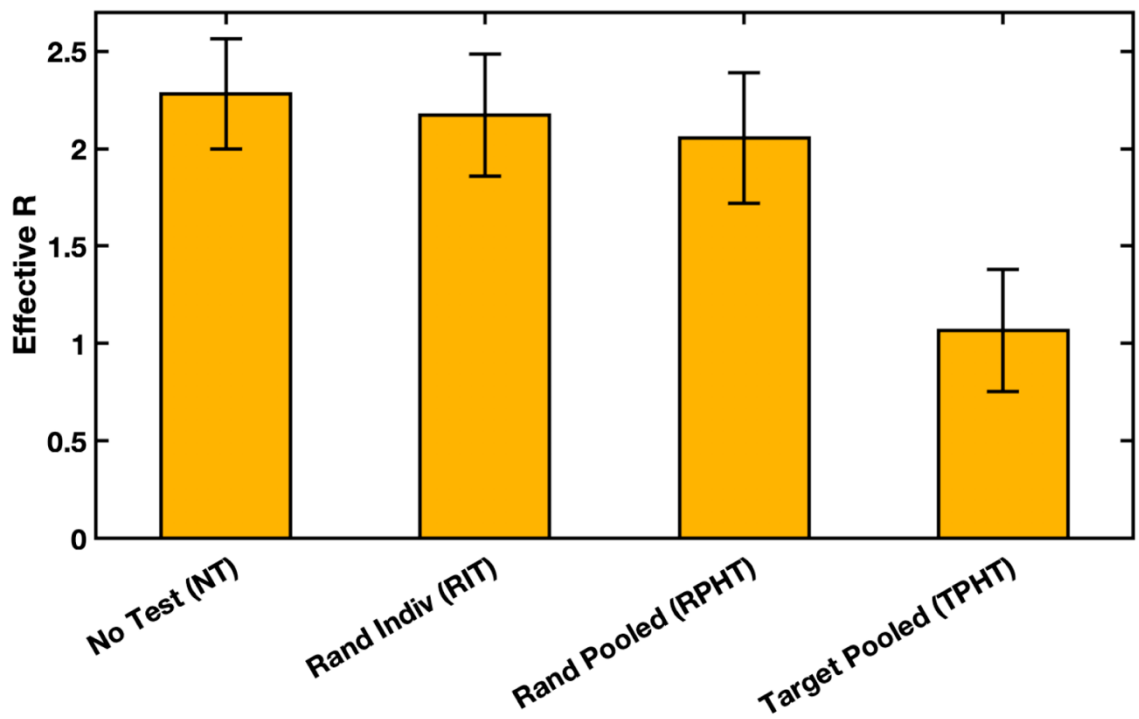
Through computer simulations we therefore contrast the following strategy

- Perform pooled tests for households, up to a given capacity and at a regular interval;
- On a positive test, the entire household is considered at risk, and therefore put in quarantine. No effort is made to identify specific positive individuals;
- The quarantine is lifted when the household clears a pooled test;
- Tests are reserved for households larger than a certain size.

which we call “Targeted Pooled Household Testing” (TPHT), with the three strategies below:

- Random pooled household testing (RPHT), which differs from TPHT only in that the tested households are chosen randomly from the entire population, not just households over a certain size;
- Random individual testing (RIT), where tests are individual, and quarantines are imposed individually;
- No testing (NT).

Results from comparisons of testing strategies



In terms of effective reproduction numbers R, we see that random testing of a moderate proportion of households only has a small effect in terms of lowering the reproduction number. Nonetheless, due to the exponential nature of epidemics, this modest reduction has a substantial impact on the number of cases over time. In contrast, the same amount of testing specifically administered towards the largest households has a much greater effect on the reproduction number, with a reduction from an average of R = 2.28 to an average of 1.07 over 72 simulations (versus an average of R = 2.06 for randomly tested households). We find randomized individual testing has a negligible effect on the reproduction number, with R = 2.17, due to the relatively small fraction (less than 10%) of the *population* tested at each interval and the time between tests (7 days) being close to the pre-/asymptomatic infectious period (typically 5-8 days), as these are the infections that are the most likely to be prevented by a positive test.

We anticipate that even 2 rounds of systematic testing according to TPHT (administered independent of those tested because of observed symptoms) will help determine spreading parameters and identify the risk of a re-growing epidemic caused by a relaxation of intervention strategies. This would allow for the identification of trends in disease prevalence to inform modeling.

While it is known that pooling of samples increases the frequency of false negatives, due to the sensitivity of the **NTNU COVID-19 test** that soon will be used for large-scale testing in Norway, this increase is anticipated to be very moderate and thus not affect our results markedly.

CONCLUSION: The comparisons of the different testing approaches unequivocally demonstrate that TPHT is a testing approach that not only serves to identify COVID-19 infected, but at the same time is a highly effective intervention strategy for breaking infection chains and thereby reducing the effective R. Our modelling suggests that testing strategies with such a two-fold purpose may serve as

an intervention strategy with low societal costs that can be employed together with high-cost initiatives or even in place of some of these initiatives.

Basic model fitting and performance

The design, construction and basic settings of our high-fidelity individual-based model (IBM) for epidemic spread in municipalities and regions in Norway is described elsewhere[1]. Briefly, we have generated an IBM based on high-resolution demographic data for municipalities in Norway. We determined model parameters by fitting the predicted hospitalization rate of our Oslo model to hospitalizations for Oslo in the period from March 1st to April 20th. We assume a sudden transition between two regimes, with infections following original "unrestricted" probabilities until March 13th. After this, all schools and daycares close, as do 50% of workplaces. Random contacts are reduced by 75%. Infection probabilities in nursing homes and within households remain the same in both regimes. Model simulations start in March and continue until June 20th, 2020.

For our simulations, we run our model from the beginning of March until April 20th. We open day care facilities on April 20th, and primary school grades 1st to 4th on April 27th. The testing strategies enter into effect on April 27th as well. We conduct our simulations with a stop-date of June 20th without any further change in strategy. For all testing strategies, we perform 50,000 tests in Oslo every 7 days. This is consistent with stated government goals of 100,000 weekly tests at the national level in late April/early May. In the TPHT strategy, tests are reserved for households consisting of 4 or more people.

As the effect of disease control measures taken at schools and day care facilities after reopening are currently unknown, the infection probabilities in these layers are set to the same as they were before the lockdown. This conservative approach is likely to cause an overestimation of the number of COVID-19 cases for the latter stages of our simulation. However, all of our 4 testing strategies are compared on equal terms, which allows for a fair comparison between them, and the ranking of effectiveness will be unaffected by reasonable variation in model parameters.

[1] https://www.ntnu.edu/biotechnology/ntnu-covid-19