Digital epidemiology

Lesson 13

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Digital contact tracing

Digital contact tracing

ARTICLE

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Digital proximity tracing on empirical contact networks for pandemic control

G. Cencetti[1,10], G. Santin[1,10], A. Longa[1,2], E. Pigani[1,3], A. Barrat[4,5], C. Cattuto[6,7], S. Lehmann[8], M. Salathé[9] & B. Lepri[1✉]

SCIENCE ADVANCES | RESEARCH ARTICLE

CORONAVIRUS

Anatomy of digital contact tracing: Role of age, transmission setting, adoption, and case detection

Jesús A. Moreno López[1,2], Beatriz Arregui García[1,2], Piotr Bentkowski[1], Livio Bioglio[3], Francesco Pinotti[1], Pierre-Yves Boëlle[1], Alain Barrat[4,5], Vittoria Colizza[1], Chiara Poletto[1]*

The efficacy of digital contact tracing against coronavirus disease 2019 (COVID-19) epidemic is debated: Smartphone penetration is limited in many countries, with low coverage among the elderly, the most vulnerable to COVID-19. We developed an agent-based model to precise the impact of digital contact tracing and household isolation on COVID-19 transmission. The model, calibrated on French population, integrates demographic, contact and epidemiological information to describe exposure and transmission of COVID-19. We explored realistic levels of case detection, app adoption, population immunity, and transmissibility. Assuming a reproductive ratio $R = 2.6$ and 50% detection of clinical cases, a ~20% app adoption reduces peak incidence by ~35%. With $R = 1.7$, >30% app adoption lowers the epidemic to manageable levels. Higher coverage among adults, playing a central role in COVID-19 transmission, yields an indirect benefit for the elderly. These results may inform the inclusion of digital contact tracing within a COVID-19 response plan.

Effect of manual and digital contact tracing on COVID-19 outbreaks: a study on empirical contact data

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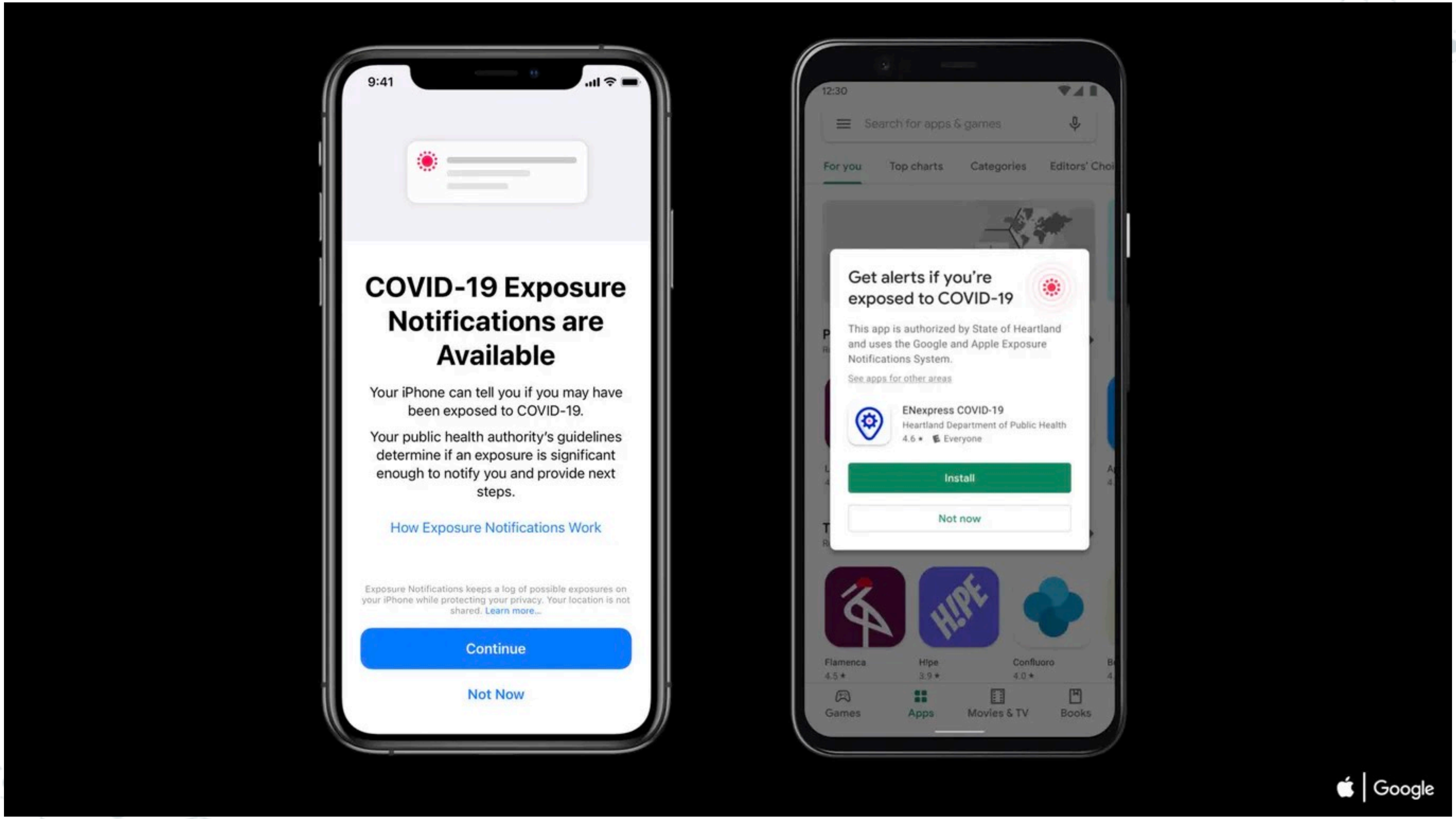
Non-pharmaceutical interventions are crucial to mitigate the COVID-19 pandemic and contain re-emergence phenomena. Targeted measures such as case isolation and contact tracing can alleviate the societal cost of lockdowns by containing the spread where and when it occurs. To assess the relative and combined impact of manual contact tracing (MCT) and digital (app-based) contact tracing, we feed a compartmental model for COVID-19 with high-resolution datasets describing contacts between individuals in several contexts. We show that the benefit (epidemic size reduction) is generically linear in the fraction of contacts recalled during MCT and quadratic in the app adoption, with no threshold effect. The cost (number of quarantines) versus benefit curve has a characteristic parabolic shape, independent of the type of tracing, with a potentially high benefit and low cost if app adoption and MCT efficiency are high enough. Benefits are higher and the cost lower if the epidemic reproductive number is lower, showing the importance of combining tracing with additional mitigation measures. The observed phenomenology is qualitatively robust across datasets and parameters. We moreover obtain analytically similar results on simplified models.

Exposure notifications



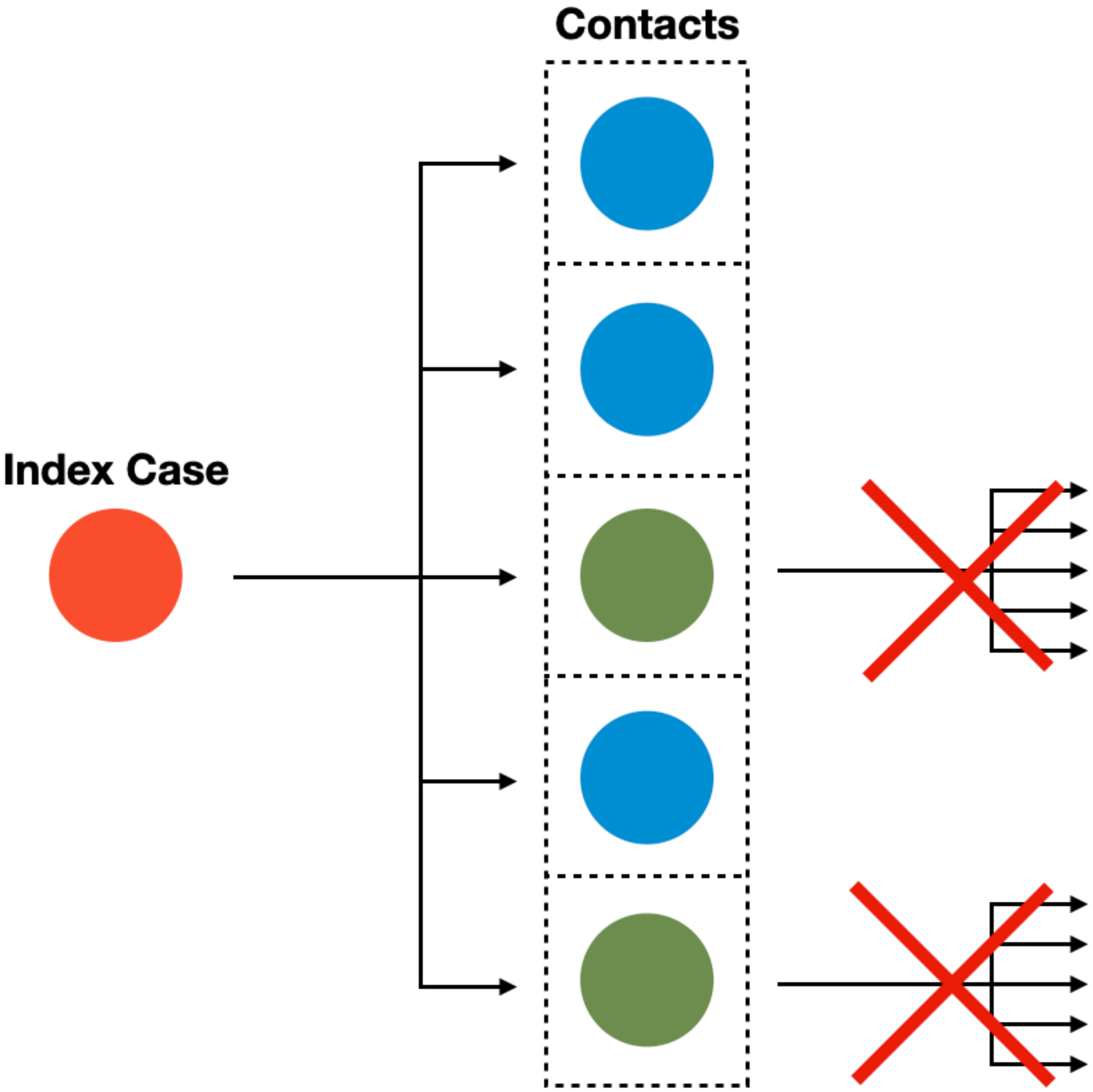
What was new?

- The COVID-19 pandemic has brought digital epidemiology to the forefront, with a particular use case: digital contact tracing.
- Digital contact tracing during the pandemic has been the **greatest roll-out of digital epidemiology technology** in the young history of the field.
- A new definition: *digital epidemiology is epidemiology that is enabled by the tools and data sources of the digital age*

Manual contact tracing

- Contact tracing is a tried and tested methodology in public health.
- The first step of contact tracing is to **identify infected individuals** through testing.
- Once an infected individual - the index case - has been identified, contact tracing aims to find the individuals who have been in contact with the index case.
- "Contact" means: there must have been a contact with the index case, ands the contact must have occurred during the infectious period of the index case.
- The main goal of contact tracing is to prevent further transmissions from the contacts as the source of the infection by quarantining the contacts.

Manual contact tracing



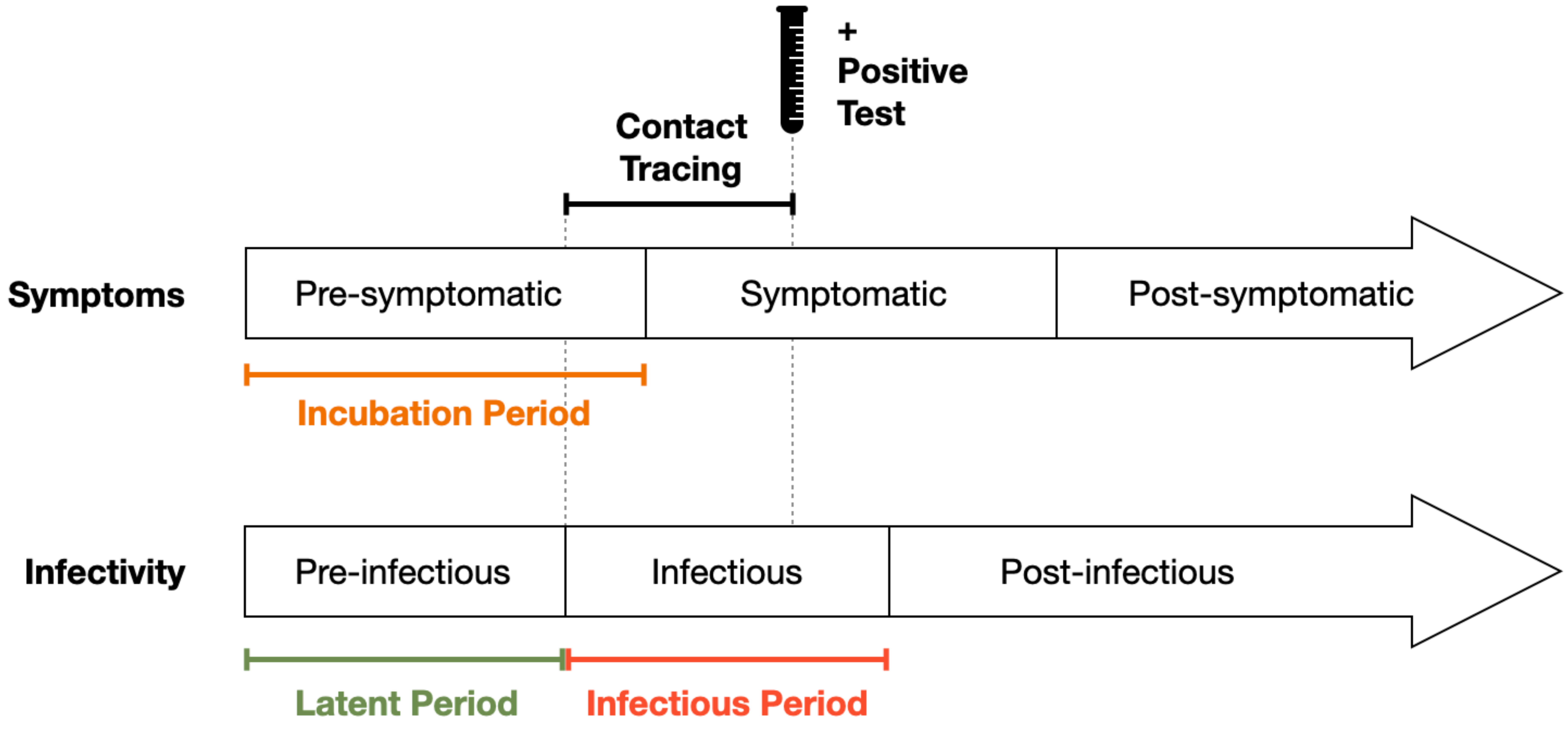
- Contacts of the index case may have already been infected, but are not yet infectious (green);
- or have not been infected at all (blue).

Manual contact tracing

- if we want to prevent all future transmission chains from the infected contacts, we need to adjust the duration of the quarantine according to the **incubation period**.

- once an exposed individual in quarantine develops symptoms, or is otherwise confirmed infected (i.e. through a test), the quarantine technically ceases to be a quarantine, and turns into isolation, which will likely go longer than the originally prescribed quarantine.

Contact tracing and COVID-19



Several challenges

- Massive scale of the effort (estimates of 100,000 tracers needed in the US by Johns Hopkins).

- Definition of contact (close proximity, distance threshold).

- Estimates of infectious period and pre-symptomatic transmission.

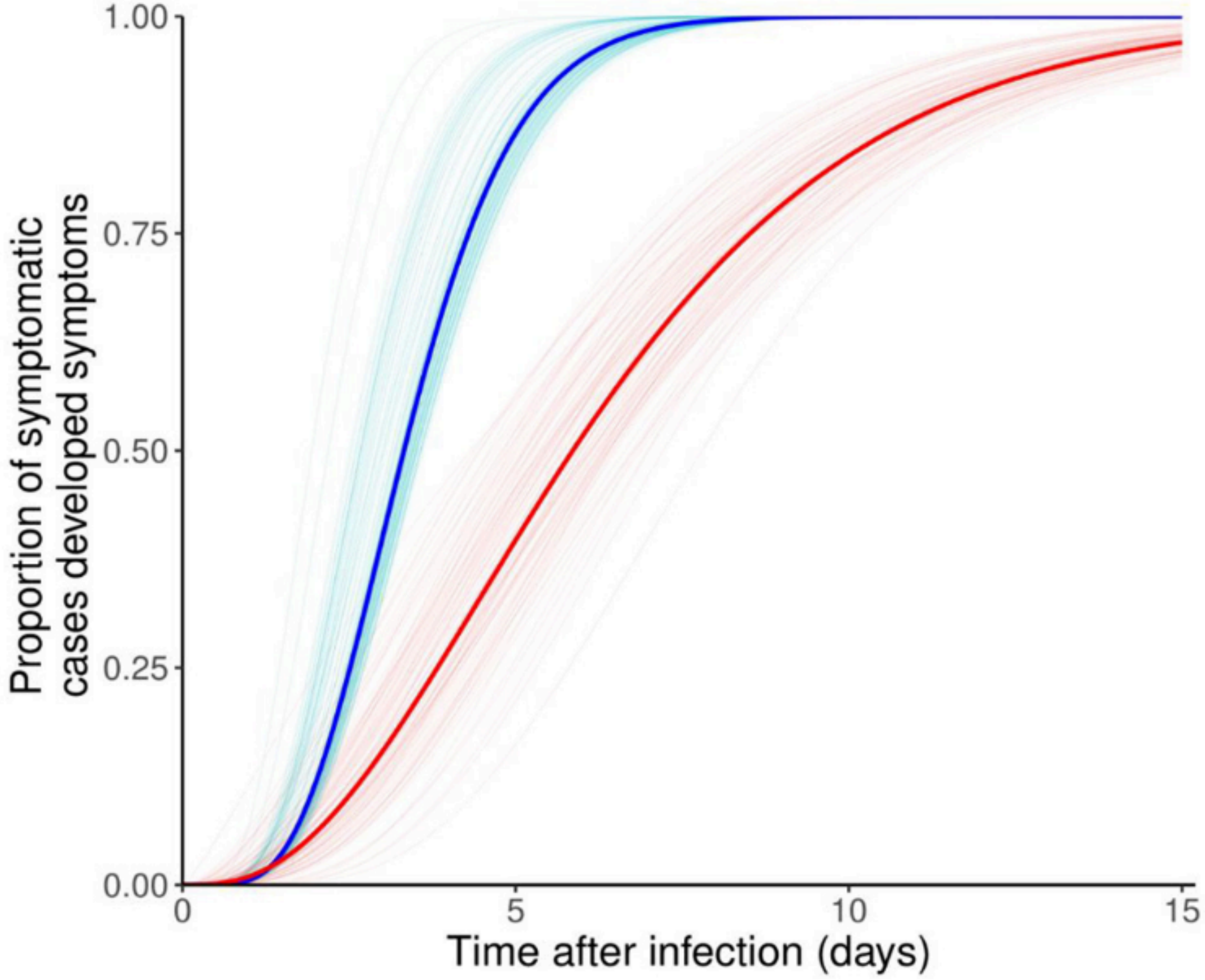
- Collecting personal information and privacy issues.

- Duration of quarantine following contact tracing.

Secondary attack rate

- The secondary attack rate, or SAR, is defined as the ratio of infection to exposure.
- If contact tracing starting from an index case identifies 10 people having been exposed, what fraction of those do we expect to have gotten infected?
- For COVID-19, this was below 20% early in the pandemic.
- A low SAR also means that many people are in quarantine even though they are not infected.
- To understand when and under which circumstances people could leave quarantine, we can look at cumulative incubation periods.

Quarantine length



- Blue: Omicron
- Red: Delta

Quarantine length was decided based on the willingness of taking risks by governments about missing potential infectious cases.

The tradeoff between medical, epidemiological, economical, and social considerations to determine quarantine length was not trivial

Digital contact tracing

- Early in the COVID-19 pandemic it was clear that manual contact tracing was too slow
- The potential use of digital means was described in a research study by Ferretti et al.

RESEARCH

RESEARCH ARTICLE SUMMARY

CORONAVIRUS

Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing

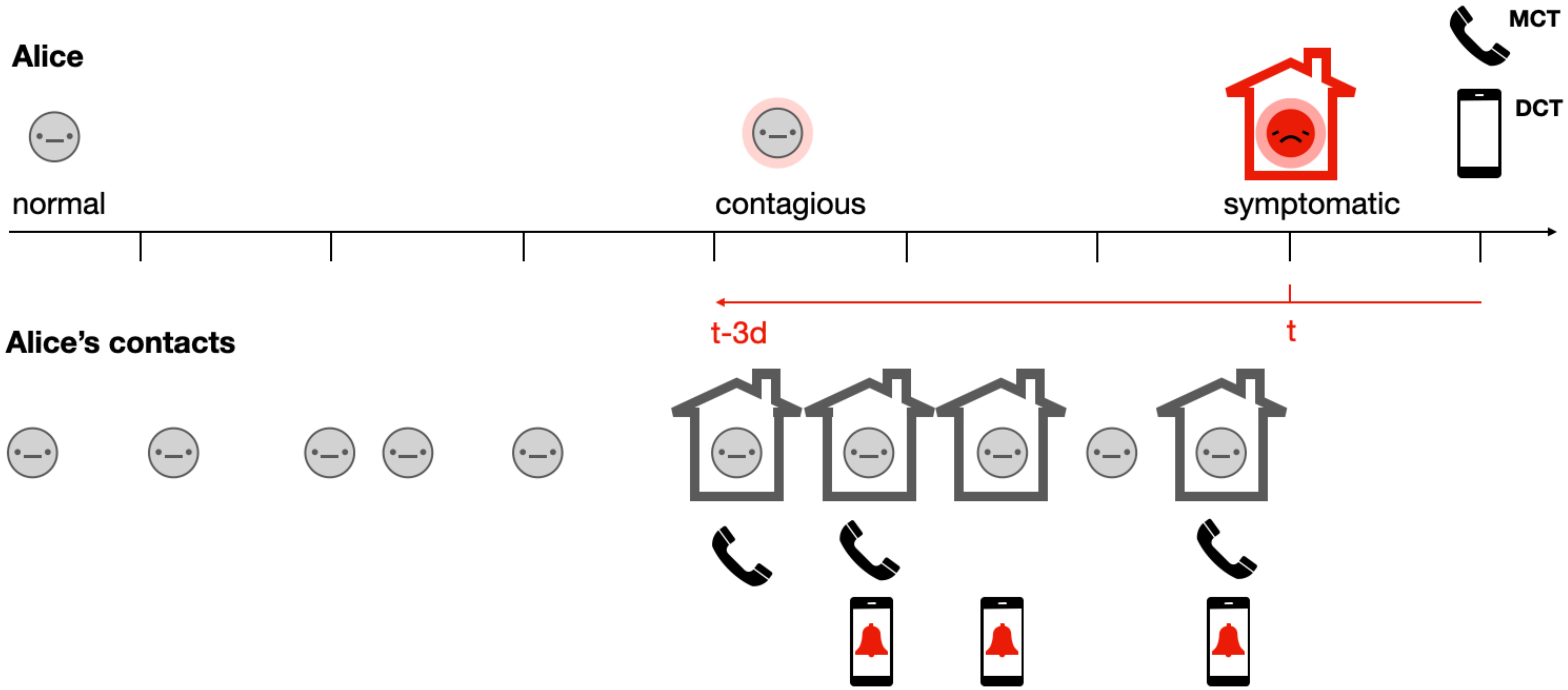
Luca Ferretti*, Chris Wymant*, Michelle Kendall, Lele Zhao, Anel Nurtay, Lucie Abeler-Dörner, Michael Parker, David Bonsall†, Christophe Fraser†‡

Challenges

- **Pro**: it speeds up efficiency of manual contact tracing with clear advantages for public health.

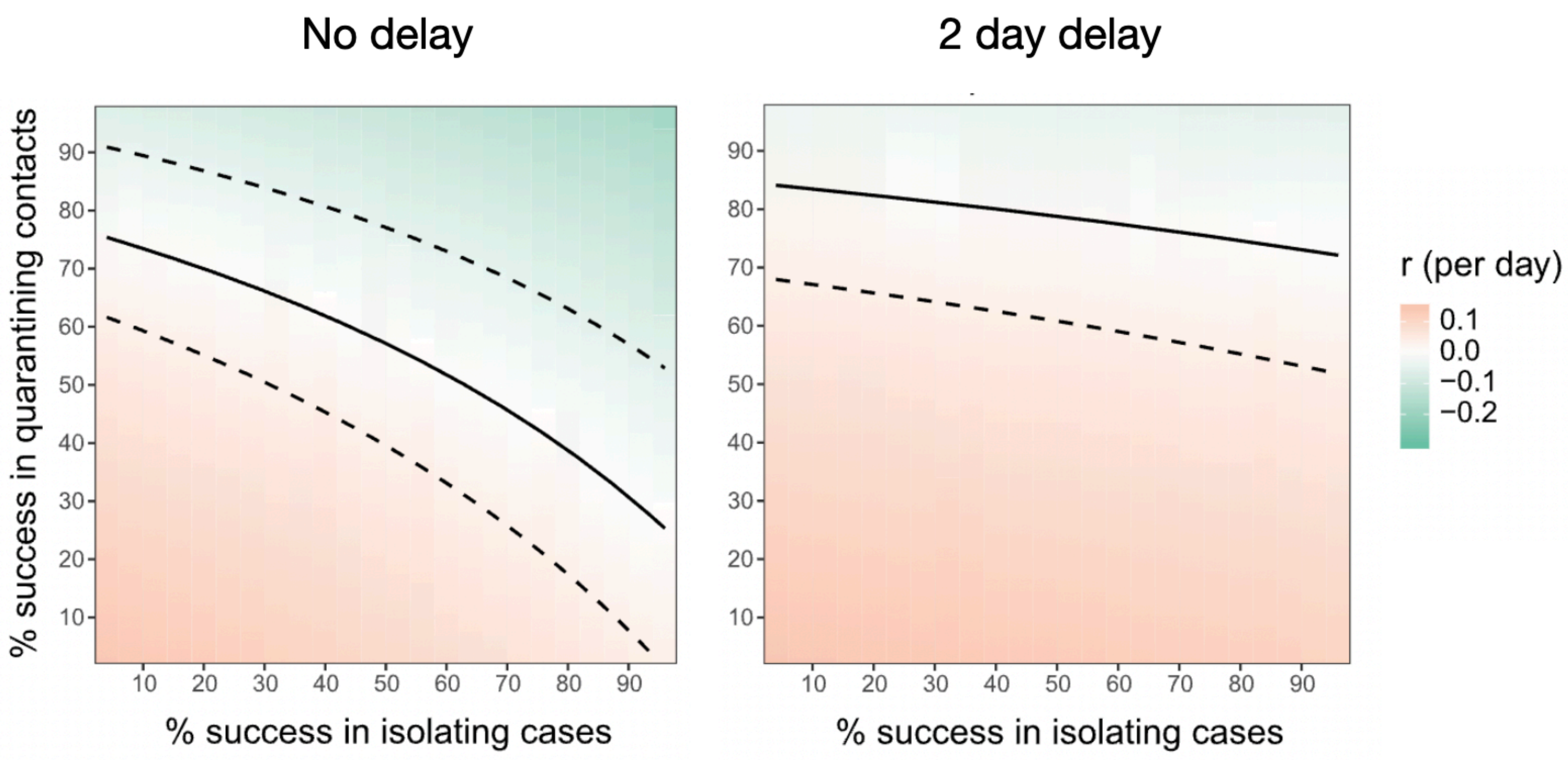
- **Cons**: substantial concerns regarding digital surveillance and misuse of collected data.

Digital Contact Tracing



Effectiveness

- Instantaneous case isolation and contact quarantine can bring the effective reproduction number below 1 even if we miss cases.
- A 2 day delay requires almost perfect success in quarantining contacts.



Ferretti et al. Science 2020

Modeling effectiveness

SCIENCE ADVANCES | RESEARCH ARTICLE

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Anatomy of digital contact tracing: Role of age, transmission setting, adoption, and case detection

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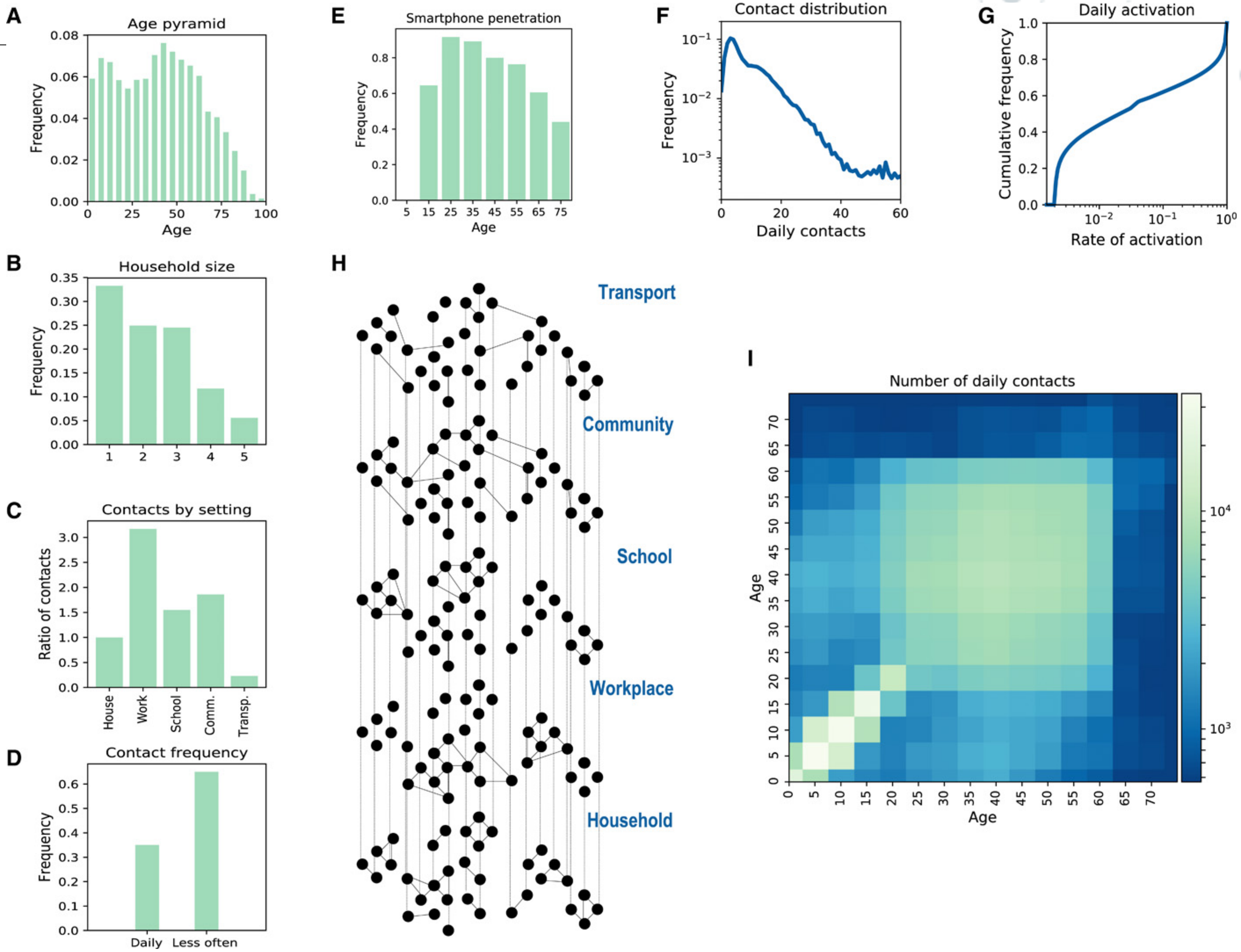
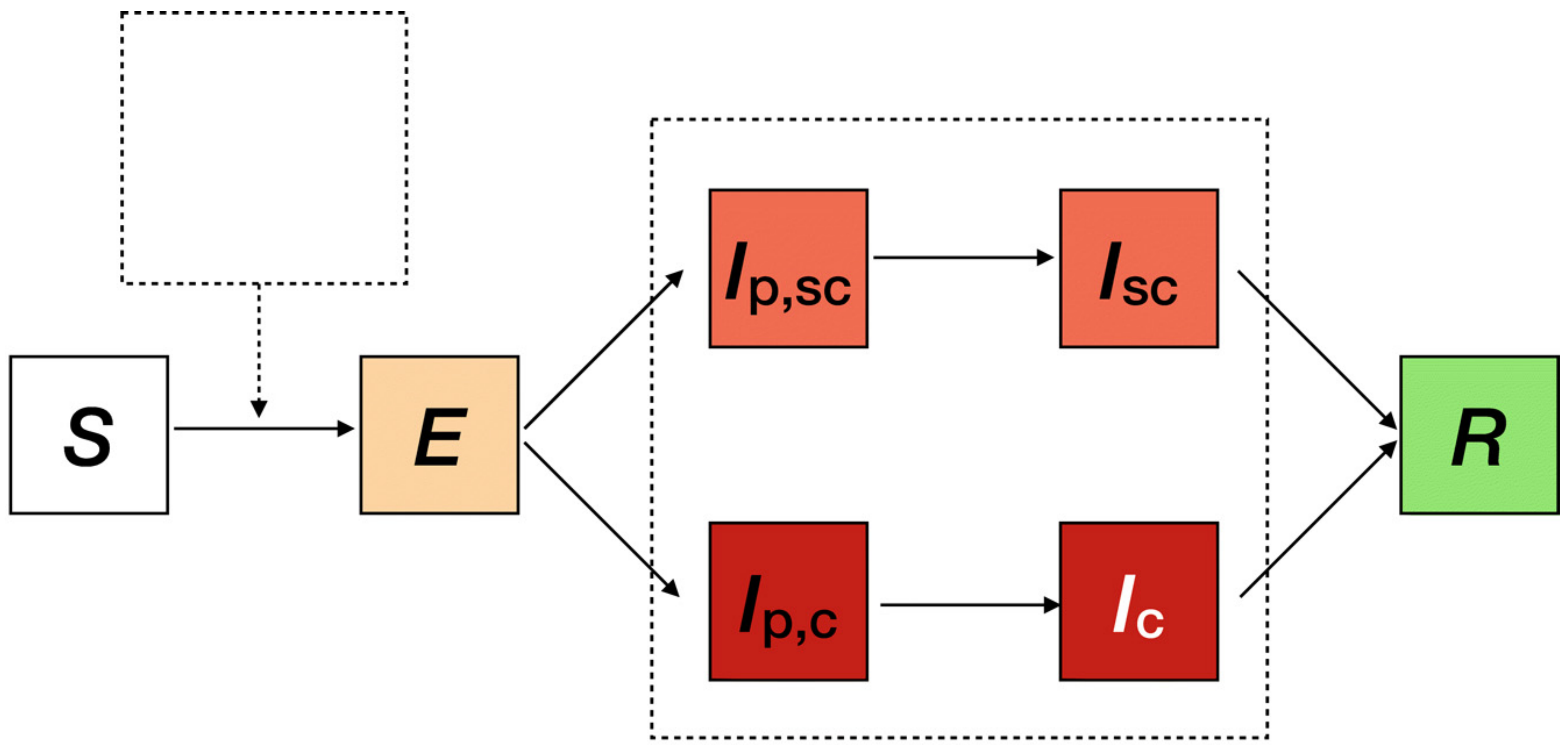
- Agent-based model for France



Modeling effectiveness

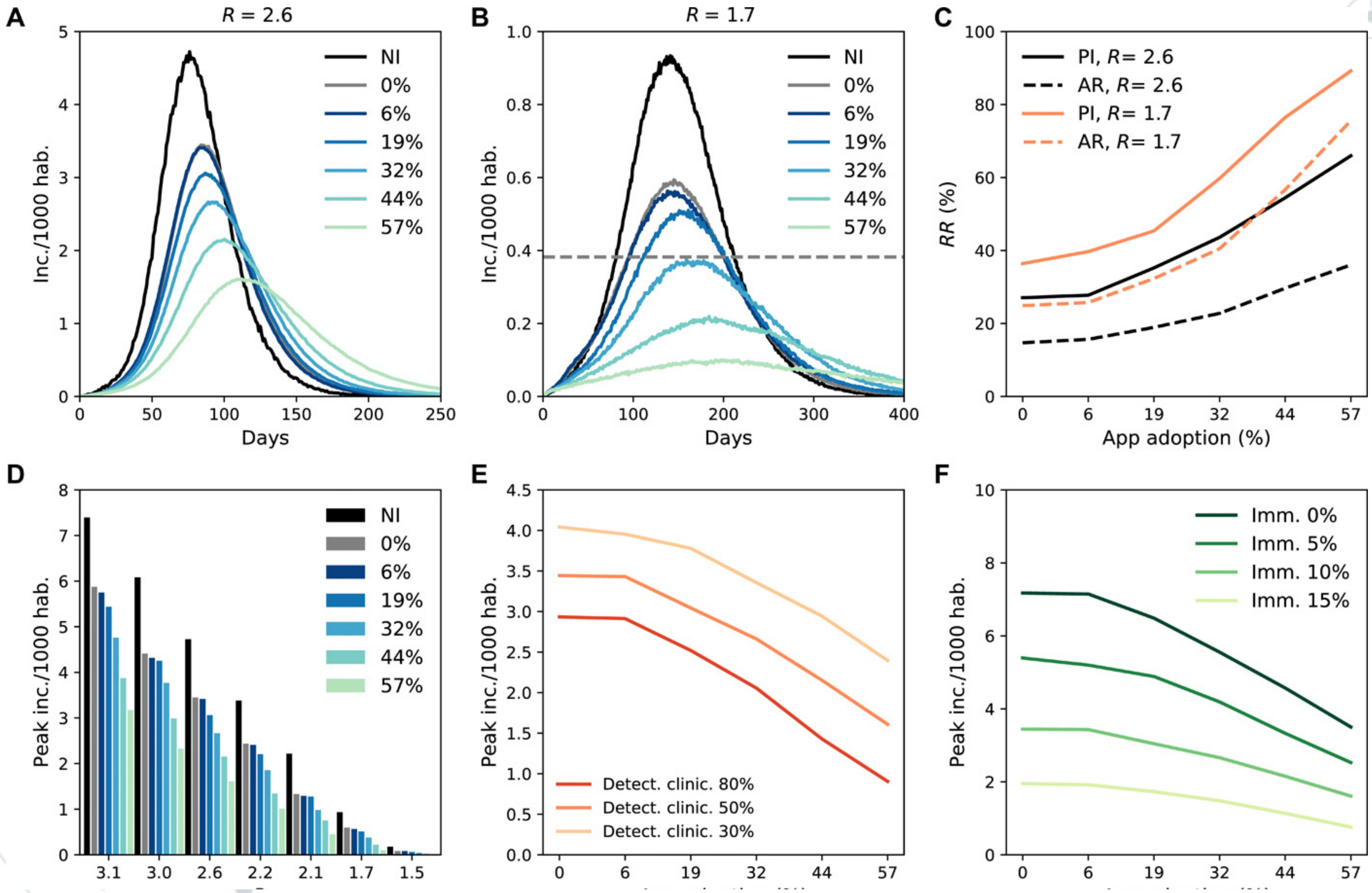
A



B

Transition	Transition rate
$S \rightarrow E$	$\beta\, \sigma_A\, \beta_I\, \omega_s$
$E \rightarrow I_{p,sc}$	$\epsilon\, p^A_{\mathrm{sc}}$
$E \rightarrow I_{p,c}$	$\epsilon\, (1 - p^A_{\mathrm{sc}})$
$I_{p,sc} \rightarrow I_{sc}$, $I_{p,c} \rightarrow I_c$	μ_{p}
I_{sc}, $I_c \rightarrow R$	μ

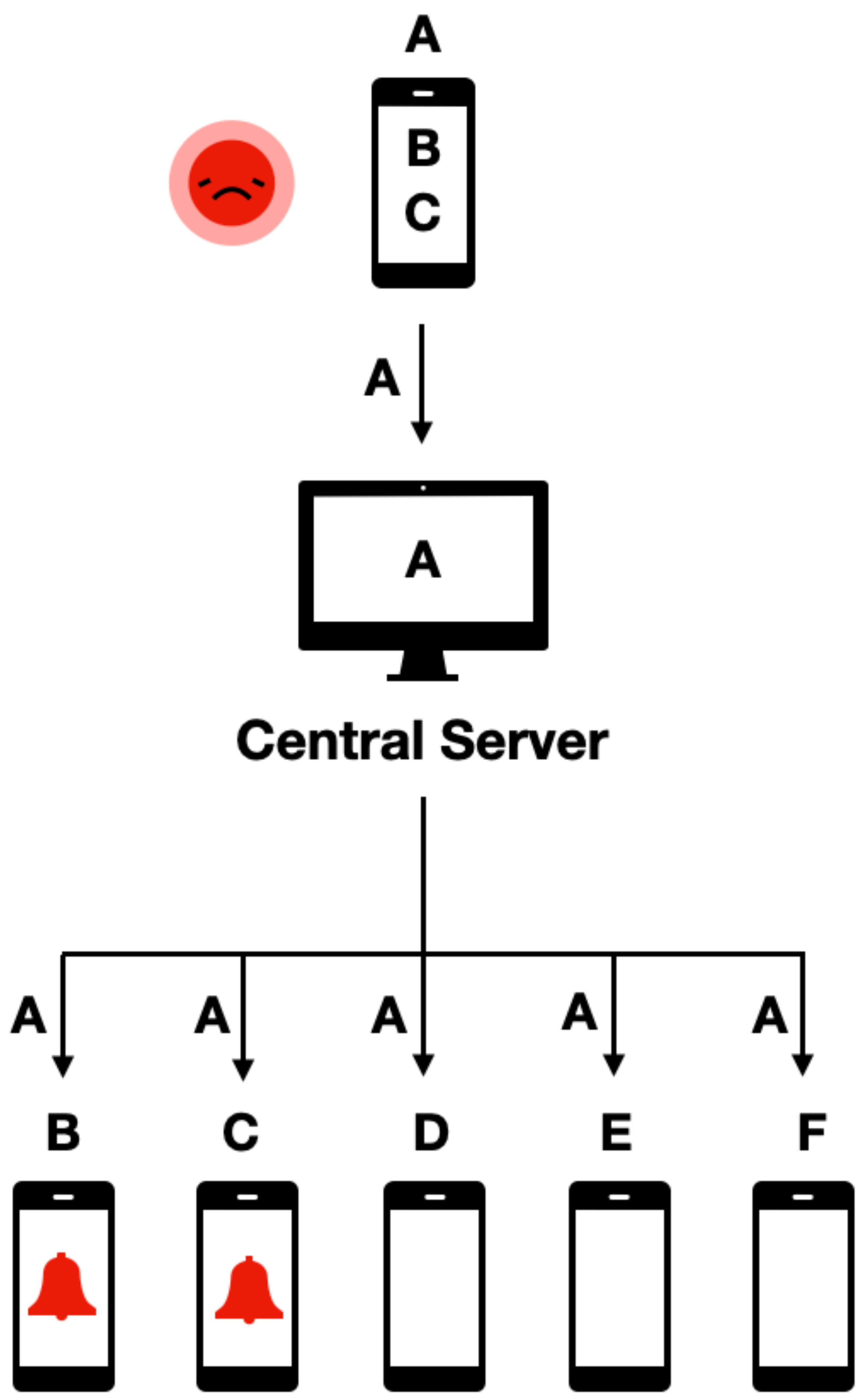
Modeling effectiveness

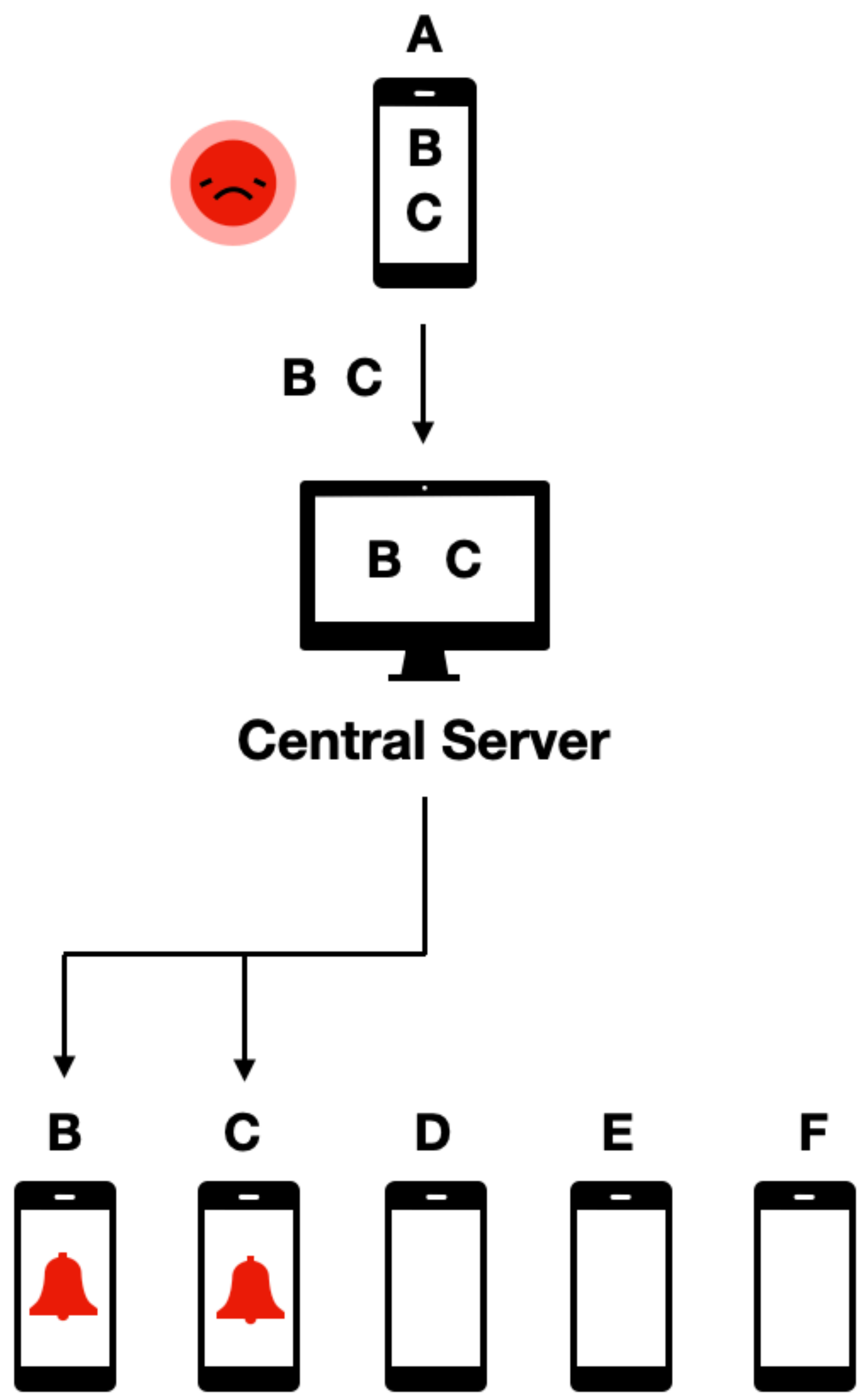


Privacy preserving protocols

- A harsh debate regarding preserving privacy in digital contact tracing. What is the ethical use of such data?
- Researchers proposed a decentralized, privacy-preserving proximity tracing protocol, or DP3T (Troncoso et al. 2020)
- In DP3T, a mobile phone continuously generates and broadcasts ephemeral, pseudo-random IDs via Bluetooth Low Energy (BLE)
- At the same time, the phone also records the pseudo-random IDs from smartphones in close proximity. The proximity itself is estimated using the strength of the recorded BLE signal.
- Importantly, before any diagnosis of COVID-19, **all the data remains on the phone.**
- This protocol was called **decentralized** because, even though a central server was part of the system, all the critical data, and the decision-making, rested decentralized on the phones.

Central vs decentral





The DP3T protocol

- Upon set up of the app, each phone generates a seed SK_t. Each day the seed is rotated by setting $SK_{t+1} = H(SK_t)$ where H is a hash function.

- The phone then generates ephemeral IDs using the seed of the day. Each *ephID* lives for a defined period of time: the epoch. If the epoch is 15 minutes, the phone generates 96 ephID each day.

- When a phone is in proximity to another phone running DP3T, it creates a local record of the day, the *ephID* and the signal strength with which the data was received.

- When a user is tested positive, the phone uploads the seed SK_{t_c} to the central server, where t_c is the first day when the user has been contagious. After the upload, the phone generates a new seed SK_t to prevent linkability with respect to previous seeds.

- In parallel, participating phones periodically download the seeds of infected users. The phones reconstruct all broadcast *ephID* and check whether they match with those recorded on the phone.

The DP3T protocol

- **Data minimisation**: all sensitive contact data stayed in the hands of app users.
- **Minimizes the risk of data abuse**: nobody would be able to get access to the data
- **Makes impossibile to track users**: central authorities would not even know that people are using the app
- **Graceful dismantling**: once users stop using the app, the system stops existing and no relevant data was stored on a central server.

Disadvantages

- **Bandwidth cost**. The central server cannot notify people who have been exposed. All users need to download the information about infected IDs and check on their phone.

- **System optimization is hard**. It is not possibile for the system to learn in real time more about how to fine-tune parameters related to the infection and use of the app.

Implementation

- **Many possible point of failures in the above process.** Test availability, public health infrastructure to handle positive results in a timely fashion, efficient reporting to individuals, app notification activated, willingness to self-isolate.

Real-world effectiveness

- **Several studies have investigated the epidemiological impact of DCT in different countries.**
- Switzerland (Salathé et al. 2020)
- Spain (Rodriguez et al. 2021)
- England and Wales (Wymant et al. 2021)

Real-world effectiveness

- 65 cases reported the SwissCovid app as the reason to get tested (they got notified): n
- 1645 CovidCodes were entered into the app by users: c
- μ, proportion of Swiss population using the app, weighted by confirmed cases per day: 16.7%

Original article

Vol. 150 No. 5153 (2020)

Early evidence of effectiveness of digital contact tracing for SARS-CoV-2 in Switzerland

Marcel Salathé, Christian L. Althaus, Nanina Anderegg, Daniele Antonioli, Tala Ballouz, Edouard Bugnion, Srdjan Čapkun, Dennis Jackson, Sang-Il Kim, James R. Larus, Nicola Low, Wouter Lueks, Dominik Menges, Cédric Moullet, Mathias Payer, Julien Riou, Theresa Stadler, Carmela Troncoso, Effy Vayena, Viktor von Wyl

$$\epsilon = \frac{n}{c\mu} \sim = 0.24$$

number of index cases entering CovidCodes scaled by the probability that their contacts use the SwissCovid app, assuming a homogeneous distribution of the app coverage.

Real-world effectiveness

- **Controlled experiment in La Gomera, Canary Islands, Spain**
- Simulated outbreaks, with individuals notified of their infection status from a control room
- Simulated final attack rate = 10%
- Measure of 7 different KPIs to assess the performance of the app

ARTICLE

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https://doi.org/10.1038/s41467-020-20817-6 OPEN

A population-based controlled experiment assessing the epidemiological impact of digital contact tracing

Pablo Rodríguez[1], Santiago Graña[2], Eva Elisa Alvarez-León[3], Manuela Battaglini[4], Francisco Javier Darias[3], Miguel A. Hernán[5,6,7], Raquel López[8], Paloma Llaneza[9], Maria Cristina Martín[8], RadarCovidPilot Group, Oriana Ramirez-Rubio[10], Adriana Romaní[10], Berta Suárez-Rodríguez[10], Javier Sánchez-Monedero[11], Alex Arenas[12] & Lucas Lacasa[13,14]✉

Real-world effectiveness

Table 1 Summary of key performance indicators and results of the population-based controlled experiment.

KPI	Result
Adoption	~33%, potentially larger based on indirect survey data.
Adherence	high during the whole duration of the experiment.
Compliance	64% of those cases that are given a code introduce it in the app.
Turnaround time	98% of those index cases that comply introduce the code within 24 h, and on average it takes 2.35 days between a simulated index case introduces a code in the app and the alerted close-contacts follow-up with call centre.
Follow-up	10% of notified close-contacts follow-up with a call to the designated point of care (call centre).
Overall detection	on average and after adequate Bluetooth calibration, the app can trace 6.3 close-contacts per index case.
Hidden detection	between 23% and 39% (depending on the survey form) of exposed close-contacts are strangers to the index case.

ARTICLE

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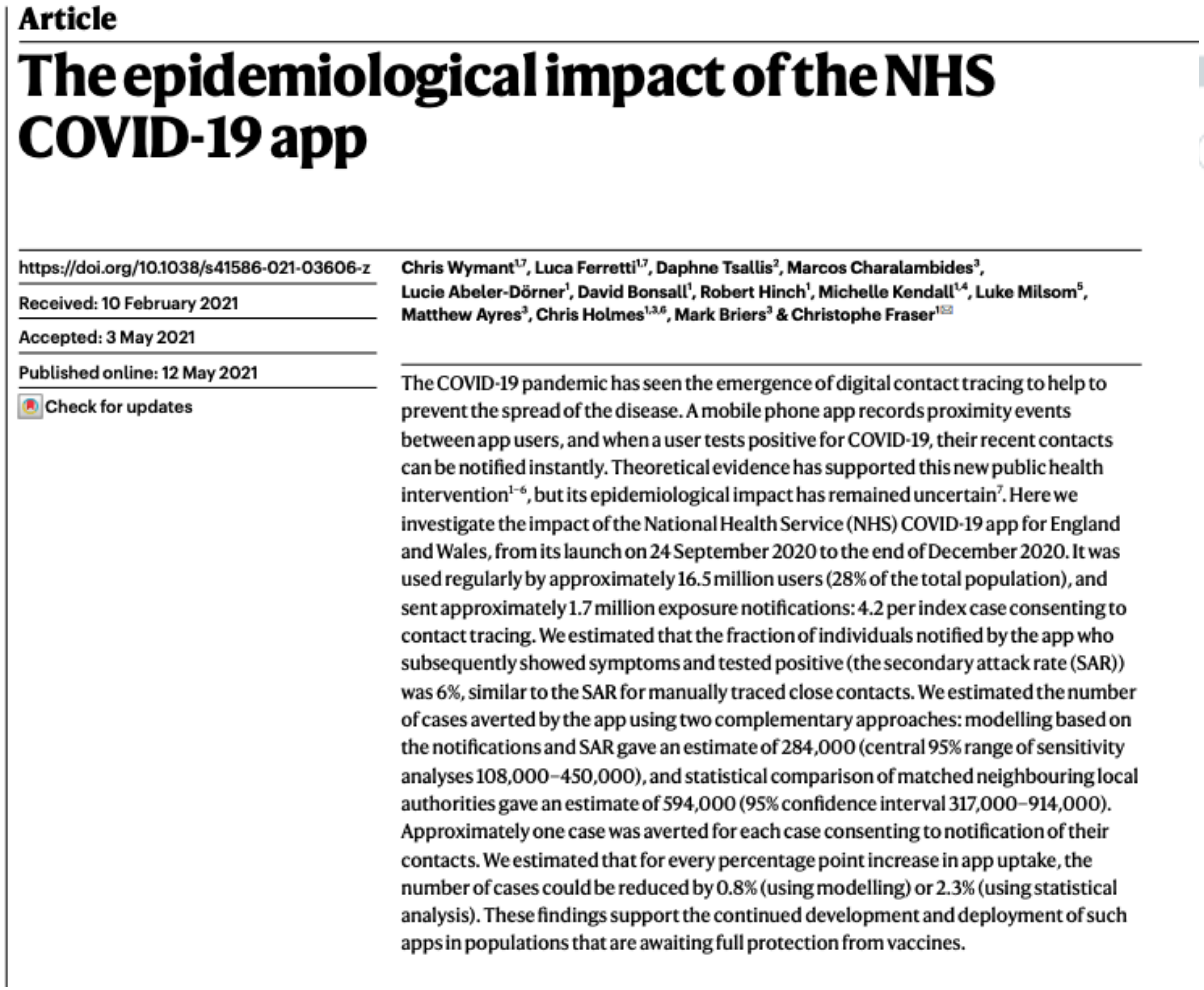
Real-world effectiveness

- 16.5 million users (28% of population
- 1.7 million exposure notifications
- 4.2 per index case consenting to contact tracing
- SAR = 6%, similar to what happens for manual contact tracing
- 284 [108-450] k cases averted by the app



Article

The epidemiological impact of the NHS COVID-19 app

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Chris Wymant[1,7], Luca Ferretti[1,7], Daphne Tsallis[2], Marcos Charalambides[3], Lucie Abeler-Dörner[1], David Bonsall[1], Robert Hinch[1], Michelle Kendall[1,4], Luke Milsom[5], Matthew Ayres[3], Chris Holmes[1,3,6], Mark Briers[3] & Christophe Fraser[1]✉

The COVID-19 pandemic has seen the emergence of digital contact tracing to help to prevent the spread of the disease. A mobile phone app records proximity events between app users, and when a user tests positive for COVID-19, their recent contacts can be notified instantly. Theoretical evidence has supported this new public health intervention[1–6], but its epidemiological impact has remained uncertain[7]. Here we investigate the impact of the National Health Service (NHS) COVID-19 app for England and Wales, from its launch on 24 September 2020 to the end of December 2020. It was used regularly by approximately 16.5 million users (28% of the total population), and sent approximately 1.7 million exposure notifications: 4.2 per index case consenting to contact tracing. We estimated that the fraction of individuals notified by the app who subsequently showed symptoms and tested positive (the secondary attack rate (SAR)) was 6%, similar to the SAR for manually traced close contacts. We estimated the number of cases averted by the app using two complementary approaches: modelling based on the notifications and SAR gave an estimate of 284,000 (central 95% range of sensitivity analyses 108,000–450,000), and statistical comparison of matched neighbouring local authorities gave an estimate of 594,000 (95% confidence interval 317,000–914,000). Approximately one case was averted for each case consenting to notification of their contacts. We estimated that for every percentage point increase in app uptake, the number of cases could be reduced by 0.8% (using modelling) or 2.3% (using statistical analysis). These findings support the continued development and deployment of such apps in populations that are awaiting full protection from vaccines.

Next… digital public health surveillance