Epidemiology of the NHS COVID-19 contact tracing app.

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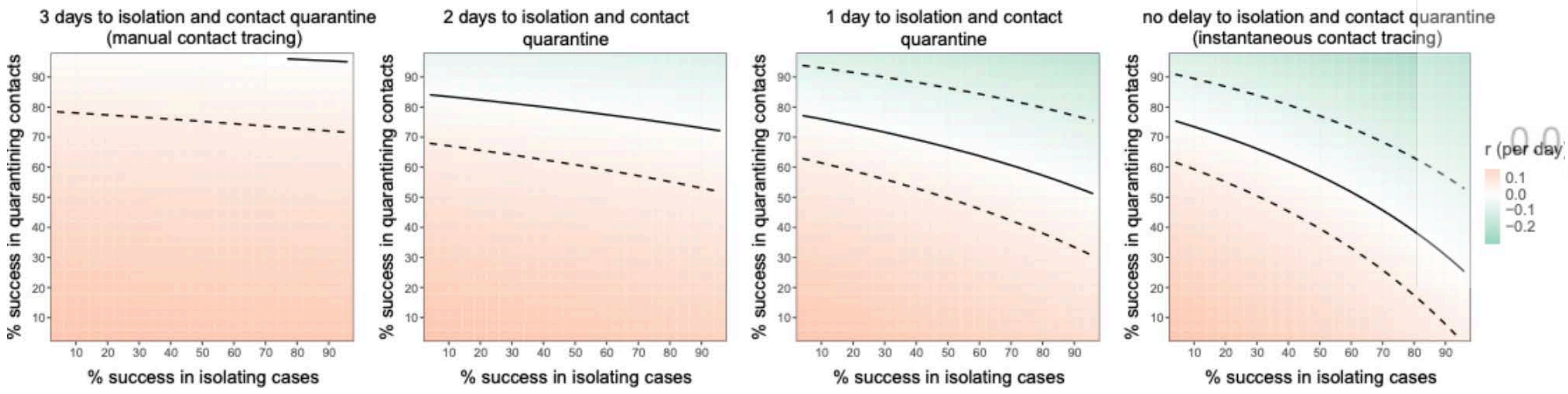
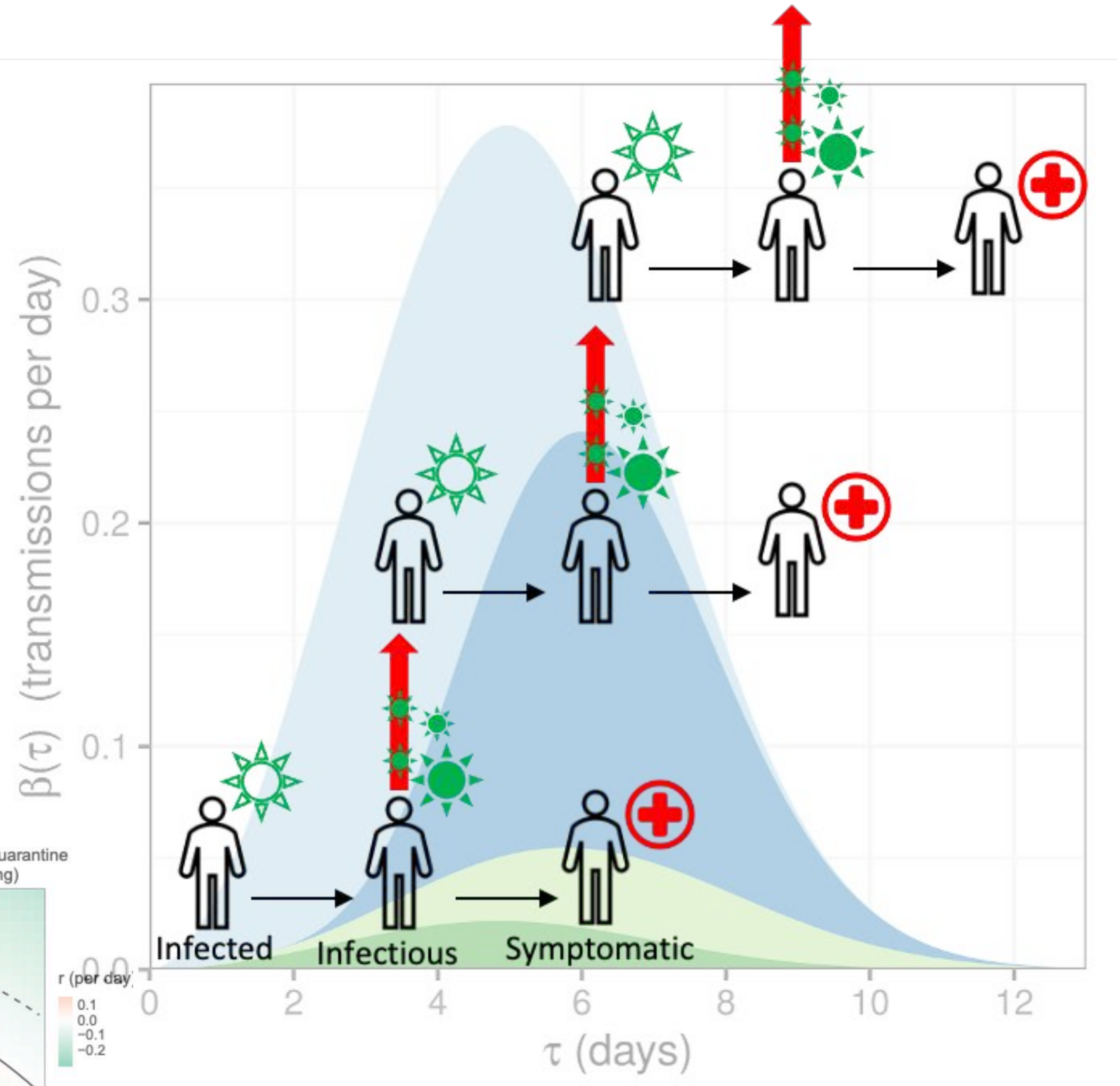
Transmission dynamics COVID-19 and contact tracing

The average time it takes for an individual to **show symptoms** = 5 - 6 days.

The average time **from infection to onward transmission** = 5 – 6 days.

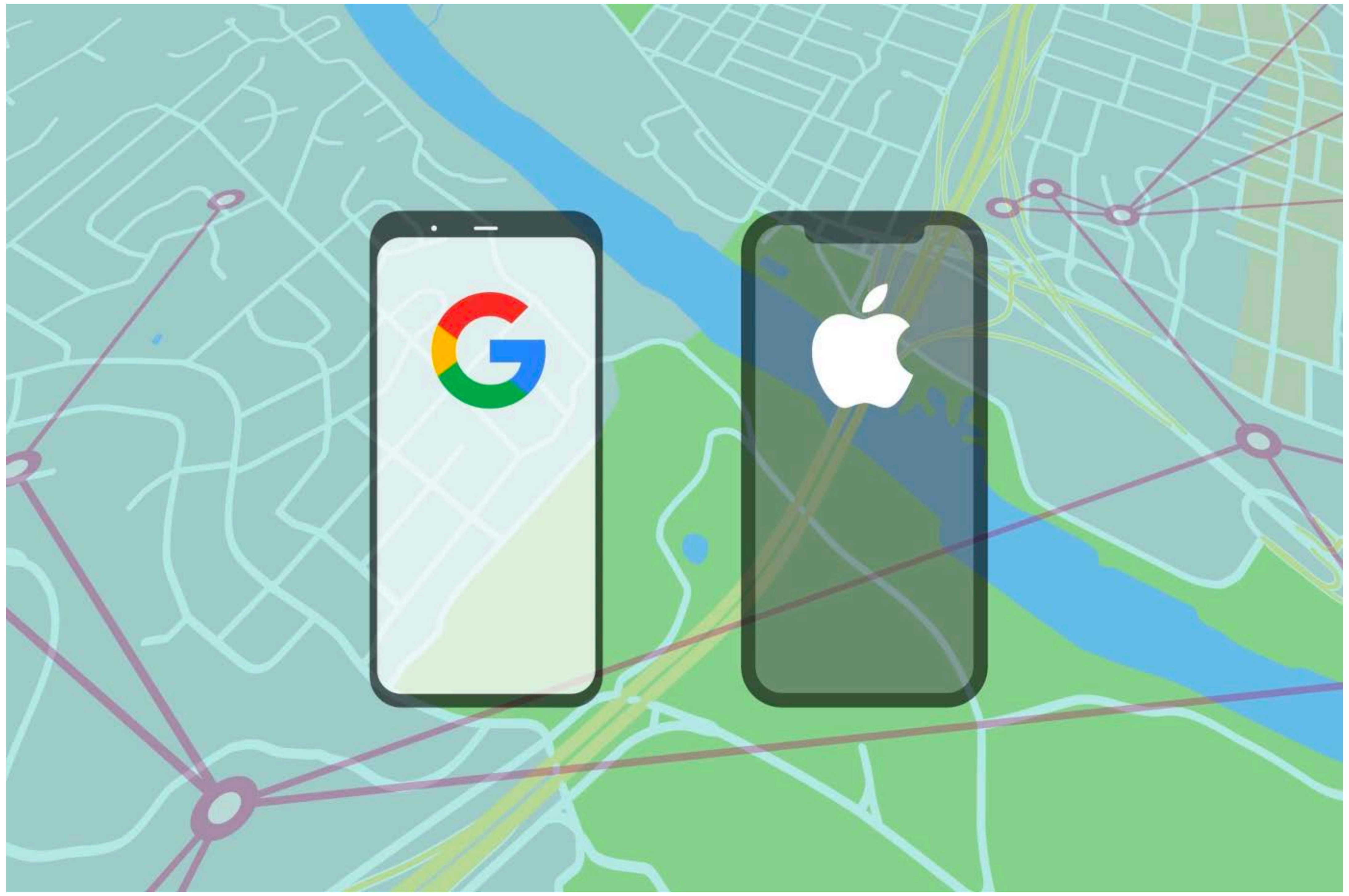
Predicted effects very **sensitive to delays** in testing and contact tracing.

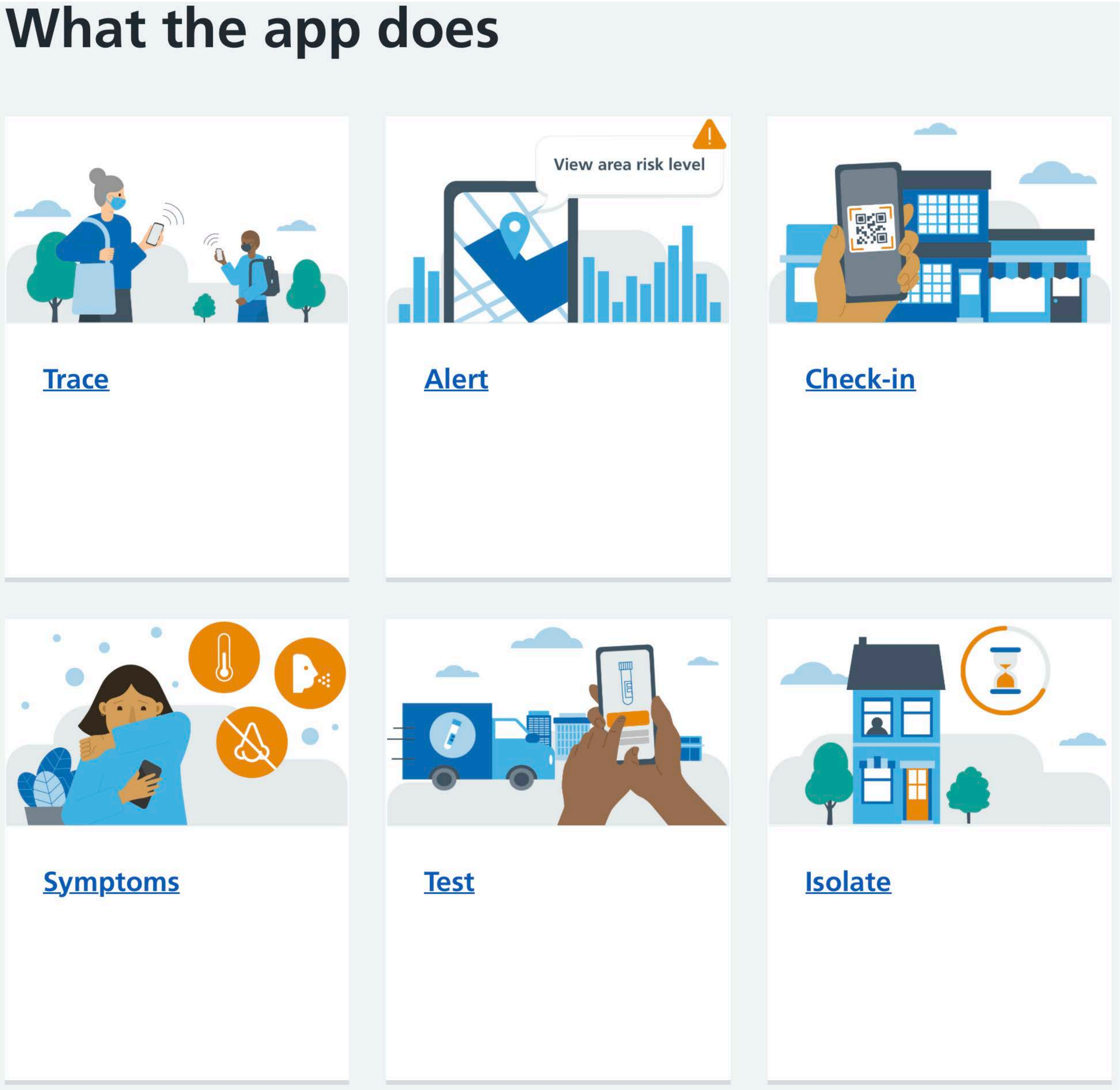




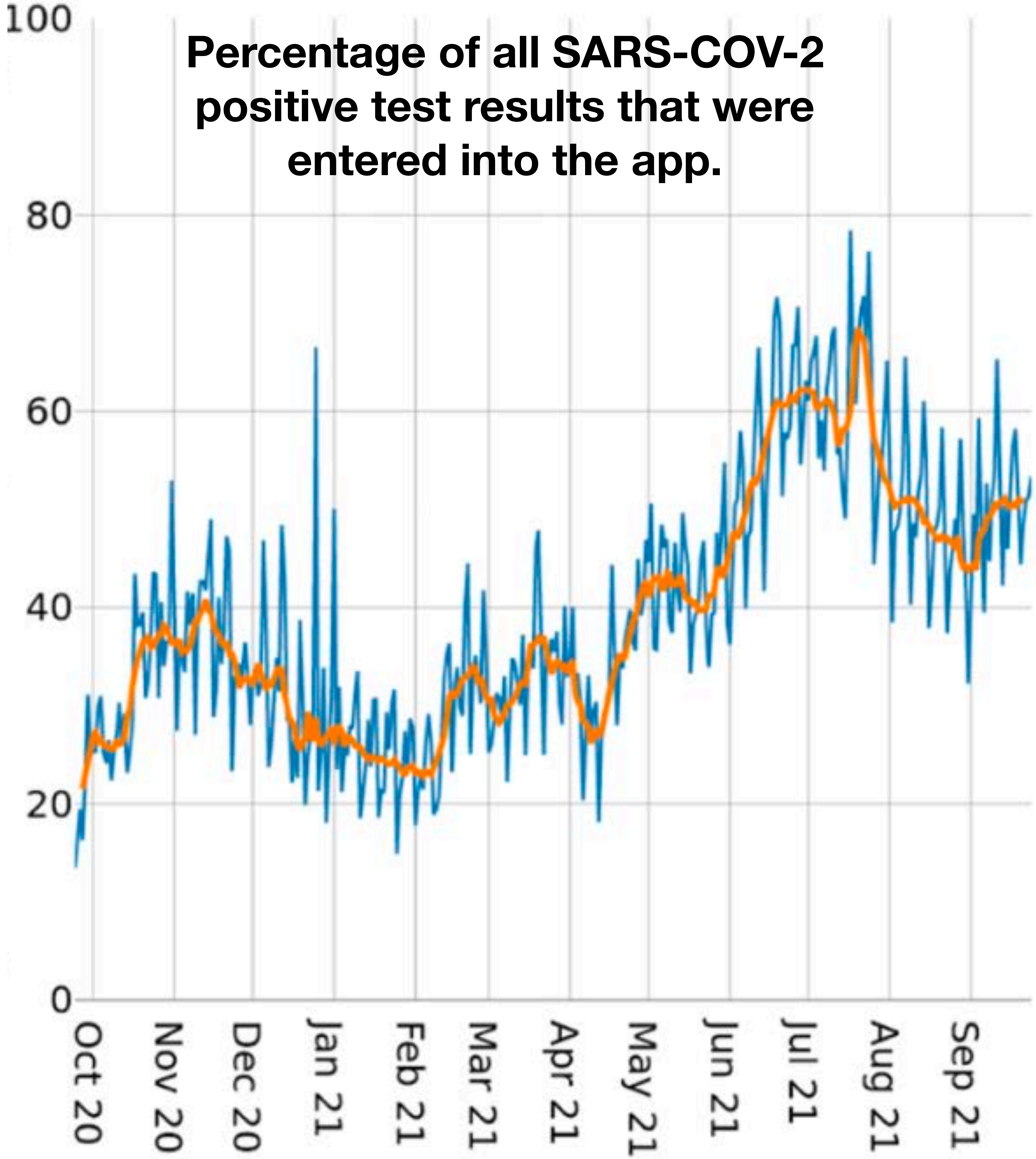
Fraser et al PNAS 2004
Ferretti et al Science 2020

Sept 2020 - UK



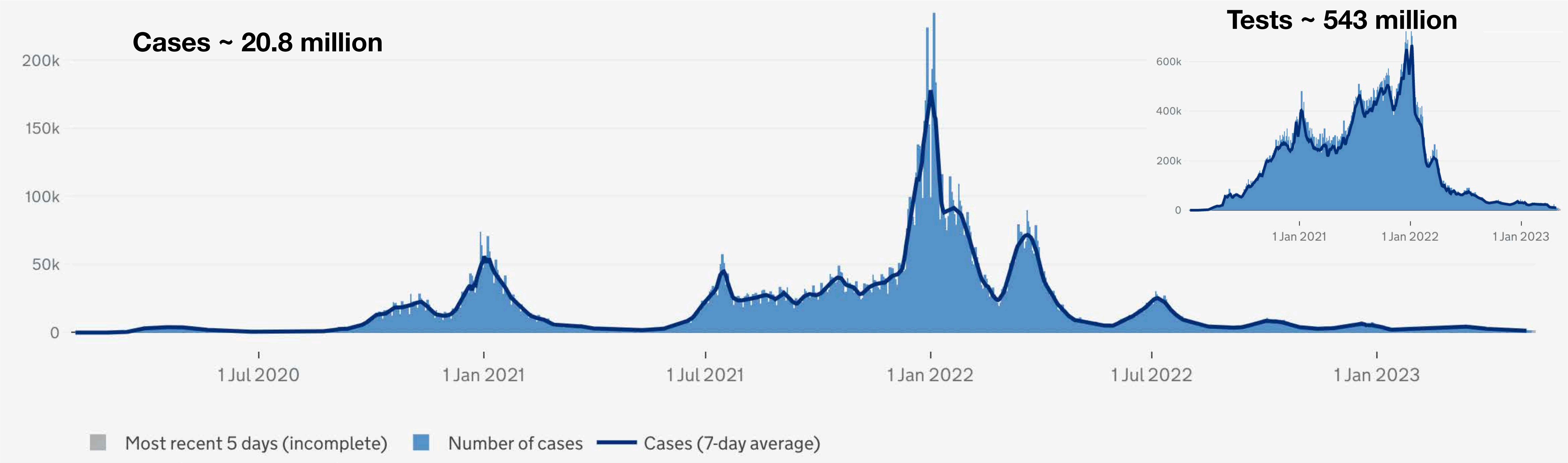


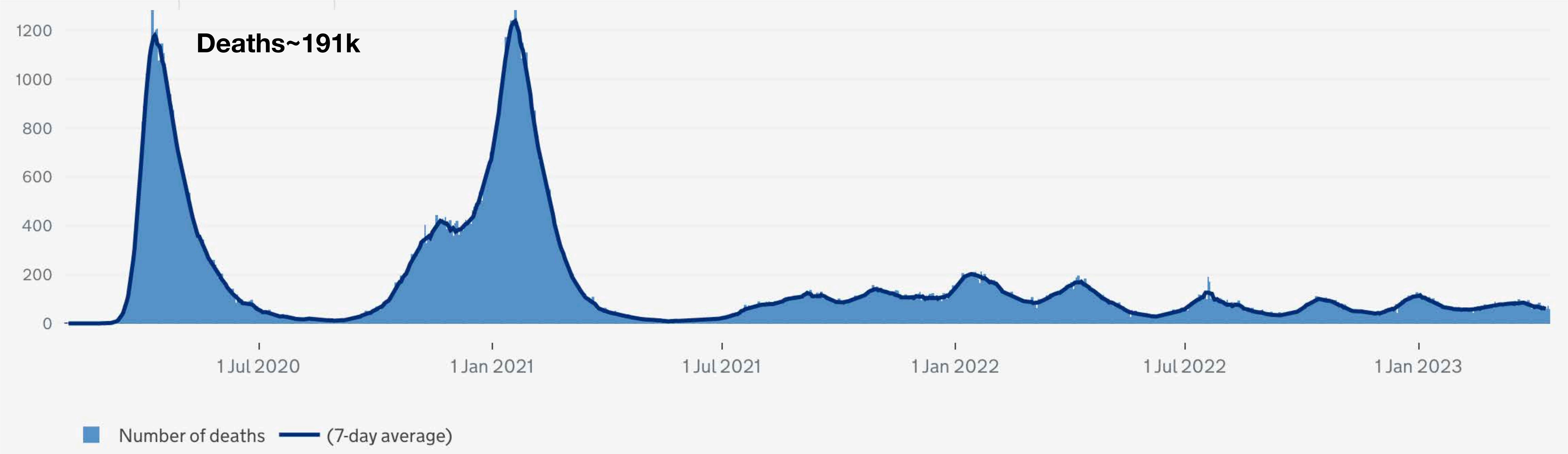
https://covid19.nhs.uk

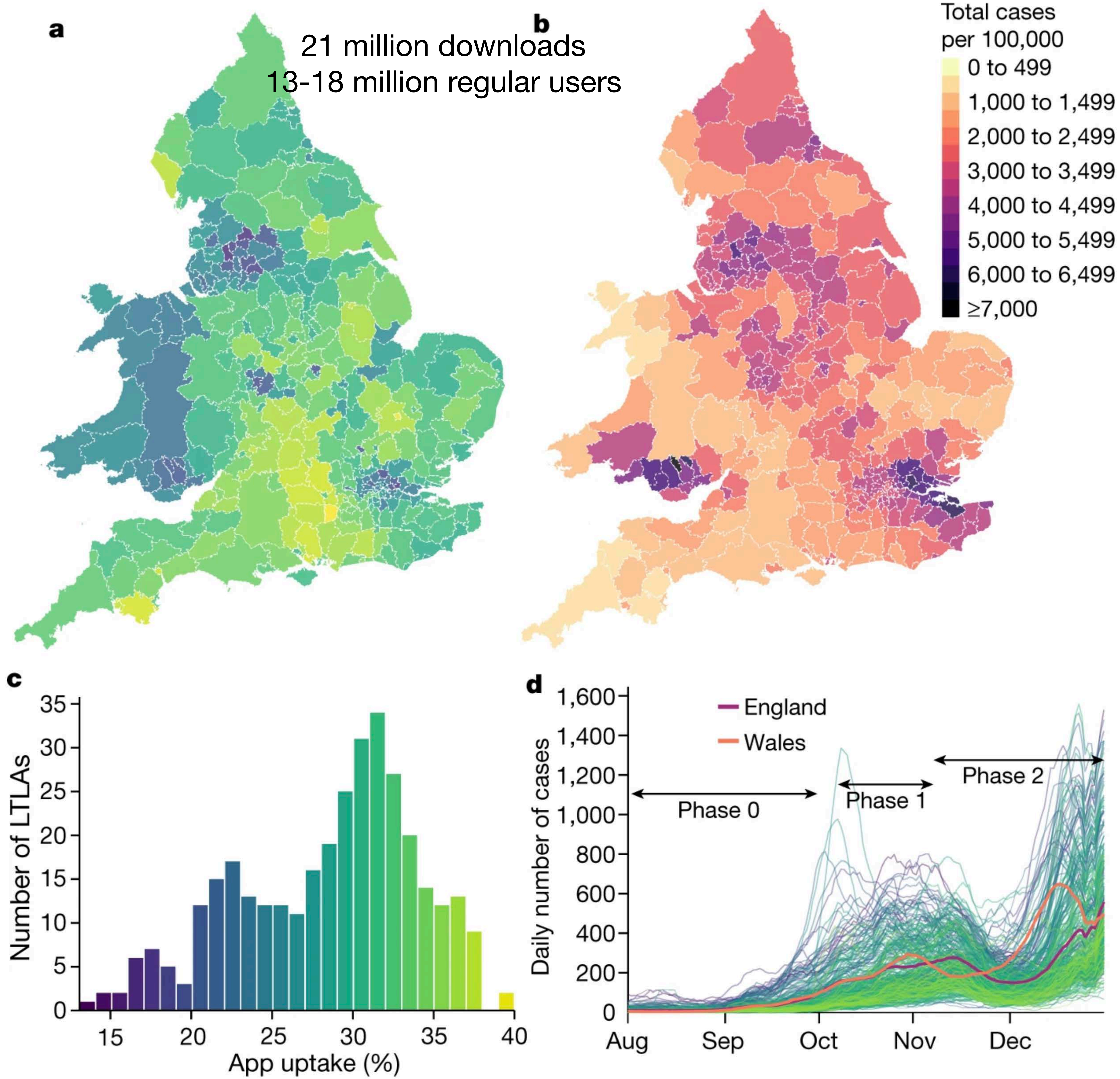


UK had centralised provision and recording of SARS-COV-2 testing

Kendall et al Nature Communications 2023


Cases ~ 20.8 million
Tests ~ 543 million
200k
150k
100k
50k
0
1 Jul 2020
1 Jan 2021
1 Jul 2021
1 Jan 2022
1 Jul 2022
1 Jan 2023
600k
400k
200k
0
1 Jan 2021
1 Jan 2022
1 Jan 2023
Most recent 5 days (incomplete)
Number of cases
Cases (7-day average)


Deaths~191k
1200
1000
800
600
400
200
0
1 Jul 2020
1 Jan 2021
1 Jul 2021
1 Jan 2022
1 Jul 2022
1 Jan 2023
Number of deaths
(7-day average)



Does having increased uptake of the app lead to fewer infections?

Uptake is heterogeneous across country. We compared 338 lower tier local health authorities in England & Wales.

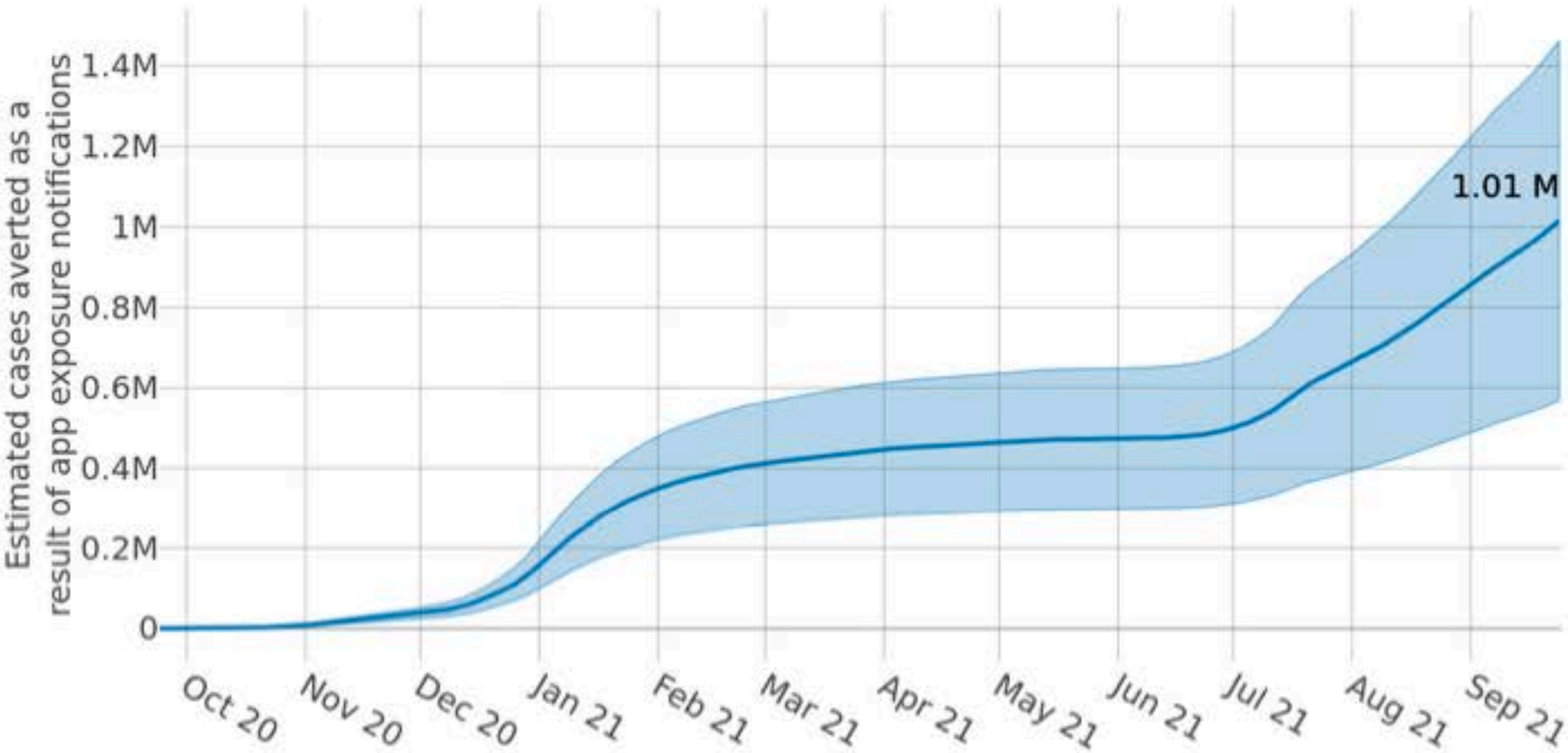
Modelling: ~300,000 cases prevented.
Causal inference ~ 600,000 cases prevented.

Modelling: ~ 0.79% reduction in cases per 1% population using app.
Causal inference: ~ 2.26% reduction in cases per 1% population using app.

Phase 1 / Phase 2 change: epidemiological effect matched changes in operational sensitivity.

Wymant, Ferretti et al Nature 2021

Modelling estimate of cases prevented (direct effects + transmission chains)



Kendall et al Nature Communications 2023

Theoretical basis for digital contact tracing

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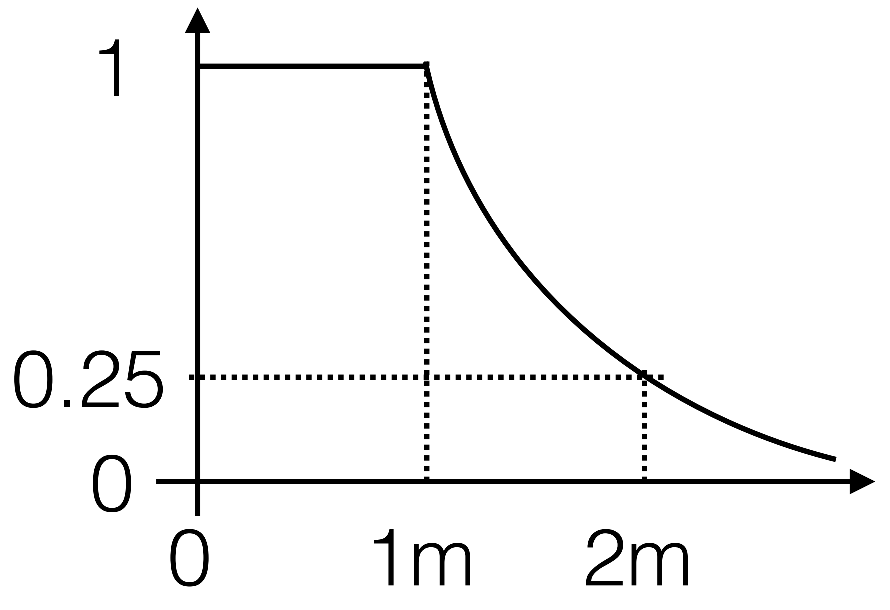
1. BLE attenuation as a measure of proximity
2. Proximity as a proxy for transmission risk:

Closer proximity = higher risk

In practice, many doubts have been expressed publicly on both these points, e.g.

1. BLE attenuation is a very noisy measure of proximity
2. Increasing understanding on the airborne transmission of SARS-CoV-2 and other viruses (including flu?)
   Transmission risk is not necessarily related to distance for airborne diseases

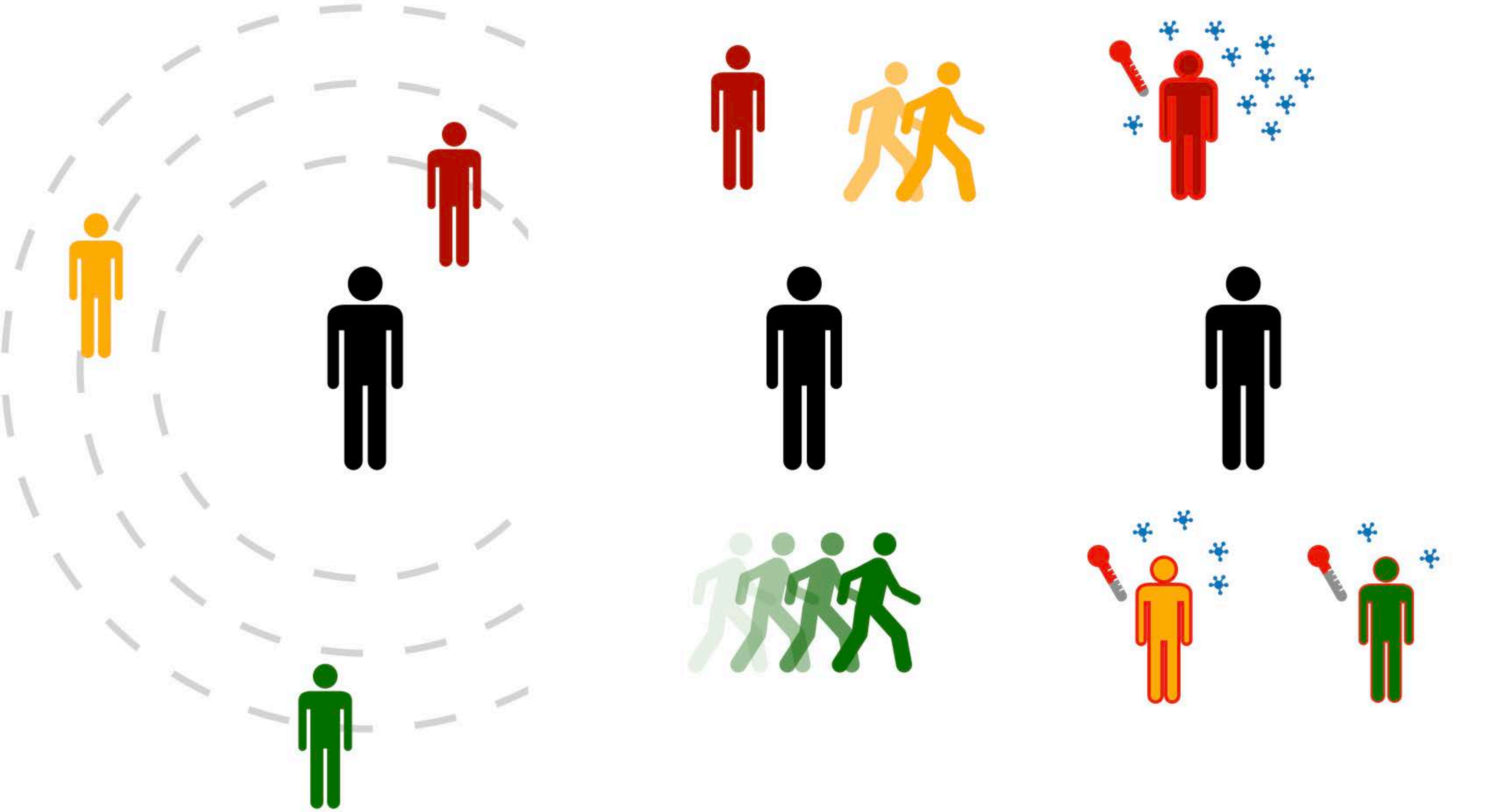
NHS COVID-19 app risk calculation, in separate 30-minute windows:



0-30
mins

2.5 if exposure in [-2, +3] days
w.r.t. index's symptoms,
1 if in [+4, +9], 0 otherwise

Risk = *proximity* × *duration* × *infectiousness*



Fraser, Ferretti, Bonsall,
Hinch, Finkelstein,
github 2020

Example data for contacts C_1, C_2, C_3 notified of risky exposure.

No data about the associated index cases except their binary infectiousness level: contacts and indices are decoupled.)

Data for each window over the threshold:

Exposed contact	Exposure window	Risk score / threshold	Proximity score	Duration / minutes	Index infectiousness	Exposure date
C_1	1	2	0.25	30	1	1/1/2022
C_1	2	8	1	30	1	1/1/2022
C_1	3	4	1	15	1	1/1/2022
C_2	1	7	1	30	2.5	2/1/2022
C_3	1	2	0.25	30	1	1/12/2021
C_3	2	1.33	0.25	20	1	2/12/2021

Outcome data for each contact:

Exposed contact	Reported positive
C_1	TRUE
C_2	FALSE
C_3	FALSE

Reported positive means via voluntary testing, entered in the app in the window [notification, 14 days since exposure]. Under-ascertainment.

We have this for *7 million* notified contacts, *23 million hours* of risky exposure.

Exposed contact	Exposure window	Risk score / threshold	Proximity score	Duration / minutes	Index infectiousness	Exposure date
C_1	1	2	0.25	30	1	1/1/2022
C_1	2	8	1	30	1	1/1/2022
C_1	3	4	1	15	1	1/1/2022
C_2	1	7	1	30	2.5	2/1/2022
C_3	1	2	0.25	30	1	1/12/2021
C_3	2	1.33	0.25	20	1	2/12/2021

Are contacts' outcomes predicted by their exposure data?

Exposed contact	Reported positive
C_1	TRUE
C_2	FALSE
C_3	FALSE

Summarise each contact's measurements
into summary metrics. e.g. here,
Max risk score = 8,
Cumulative risk score = 14,
Cumulative duration = 75 mins

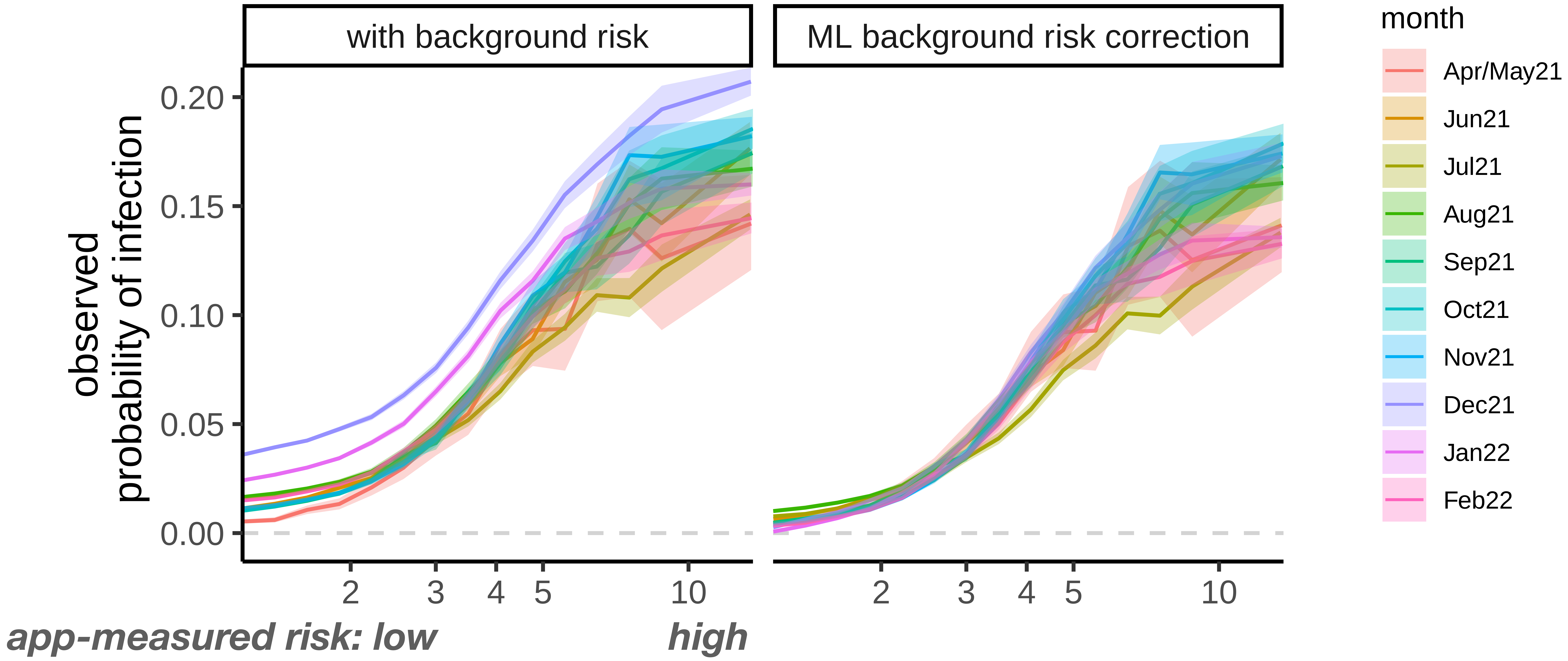
Exposed contact	Exposure window	Risk score / threshold	Proximity score	Duration / minutes	Index infectiousness	Exposure date
C_1	1	2	0.25	30	1	1/1/2022
C_1	2	8	1	30	1	1/1/2022
C_1	3	4	1	15	1	1/1/2022
C_2	1	7	1	30	2.5	2/1/2022
C_3	1	2	0.25	30	1	1/12/2021
C_3	2	1.33	0.25	20	1	2/12/2021

Exposed contact	Reported positive
C_1	TRUE
C_2	FALSE
C_3	FALSE

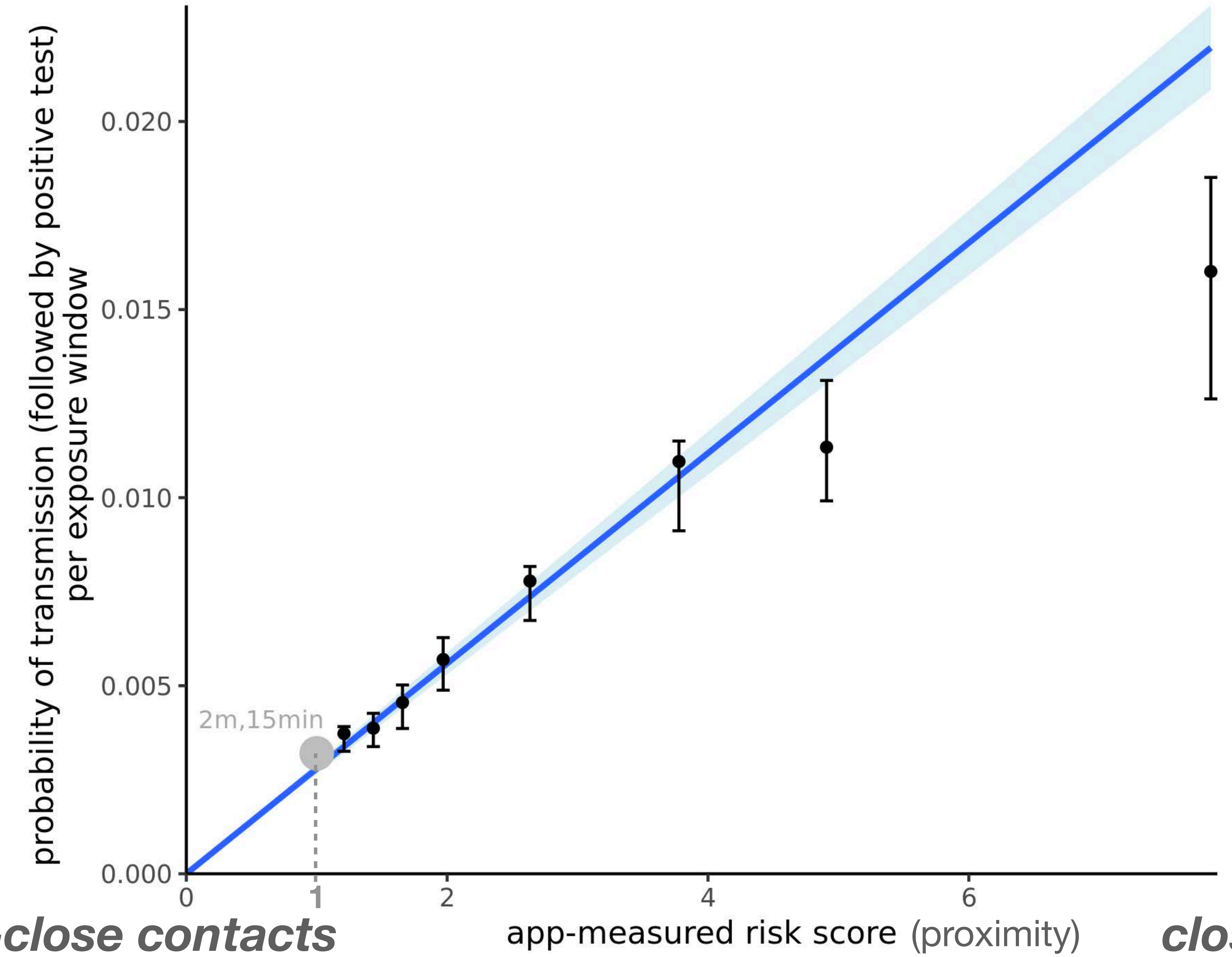
Then group/bin contacts by their metric value, and
calculate the fraction reporting a positive test =
"observed probability of infection".

Observed probability of infection
maximum risk score
cumulative risk score
duration (hours)
95% CI!
0.20
0.15
0.10
0.05
0.00
2m,15min
1
3
10
100
risk predictor
month
Apr/May21
Jun21
Jul21
Aug21
Sep21
Oct21
Nov21
Dec21
Jan22
Feb22
0.25
5
30
300
background risk

Empirical risk of infection/transmission versus app "risk score" from riskiest window



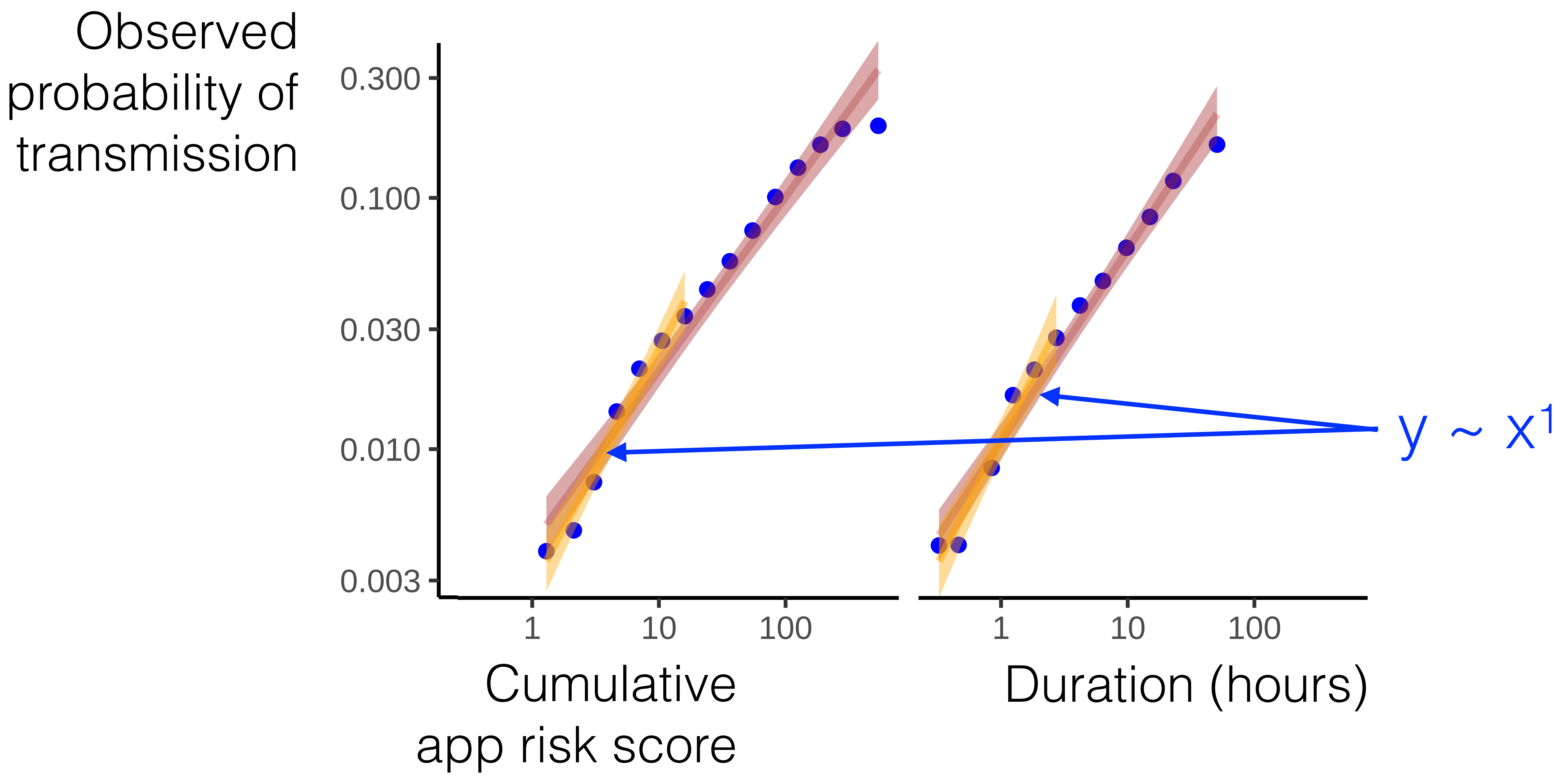
Risk of transmission from single exposure window

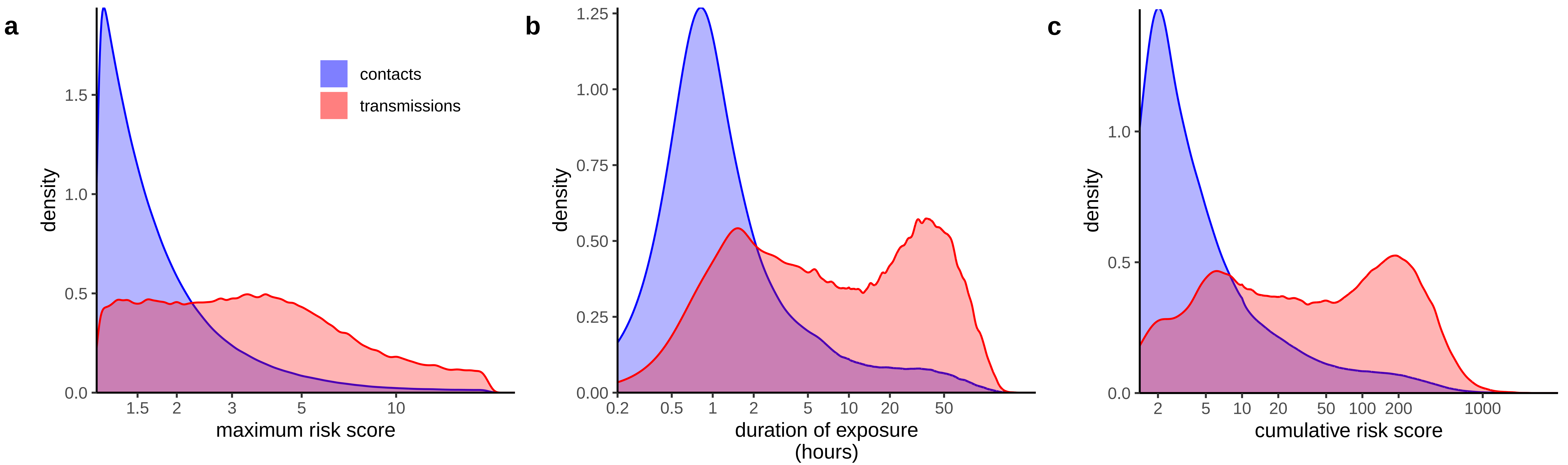


not-so-close contacts

close contacts

Estimate & subtract the background risk, attributing remaining positive tests in each bin to the recorded exposures: “transmissions”



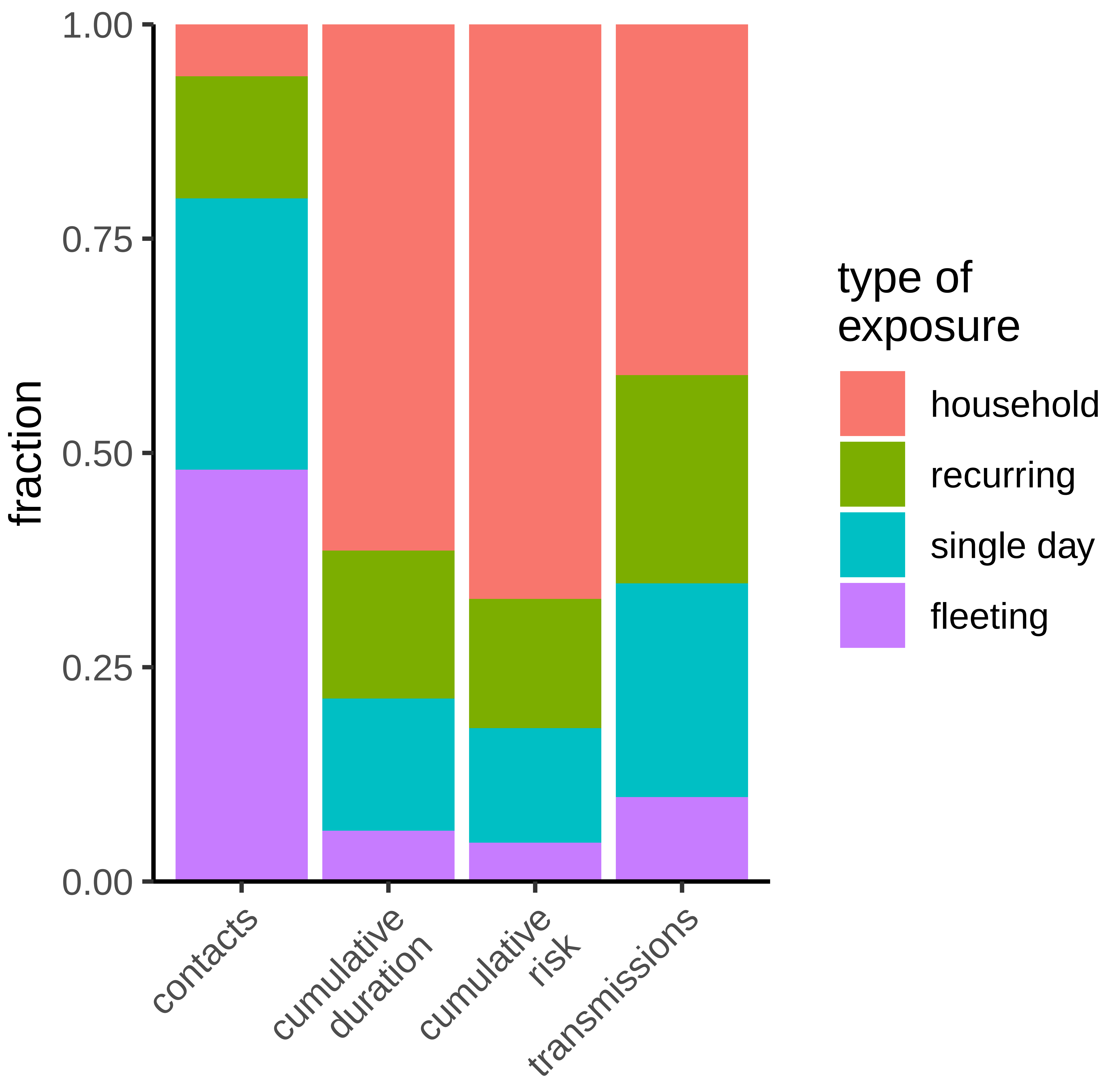


Classification of exposures

Using extra information available due to linkage between exposures:
days of exposure & total duration of exposure during each day

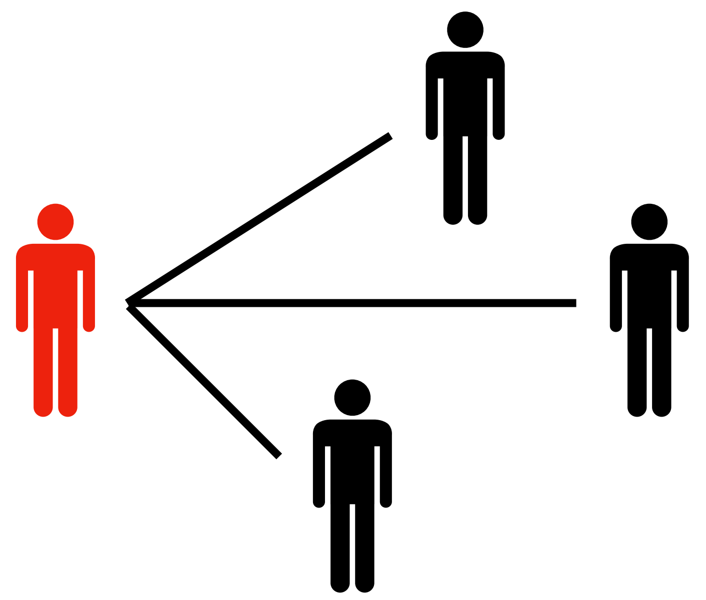
Classification:

- ***Household***: >8 hours in the same day; i.e. living together/sharing bedroom
- ***Recurring***: non-household, >30 mins total, on multiple day; may be workplaces, friends/relatives or regular activities
- ***One-day***: non-household, >30 mins total, on a single day
- ***Fleeting***: <30 mins



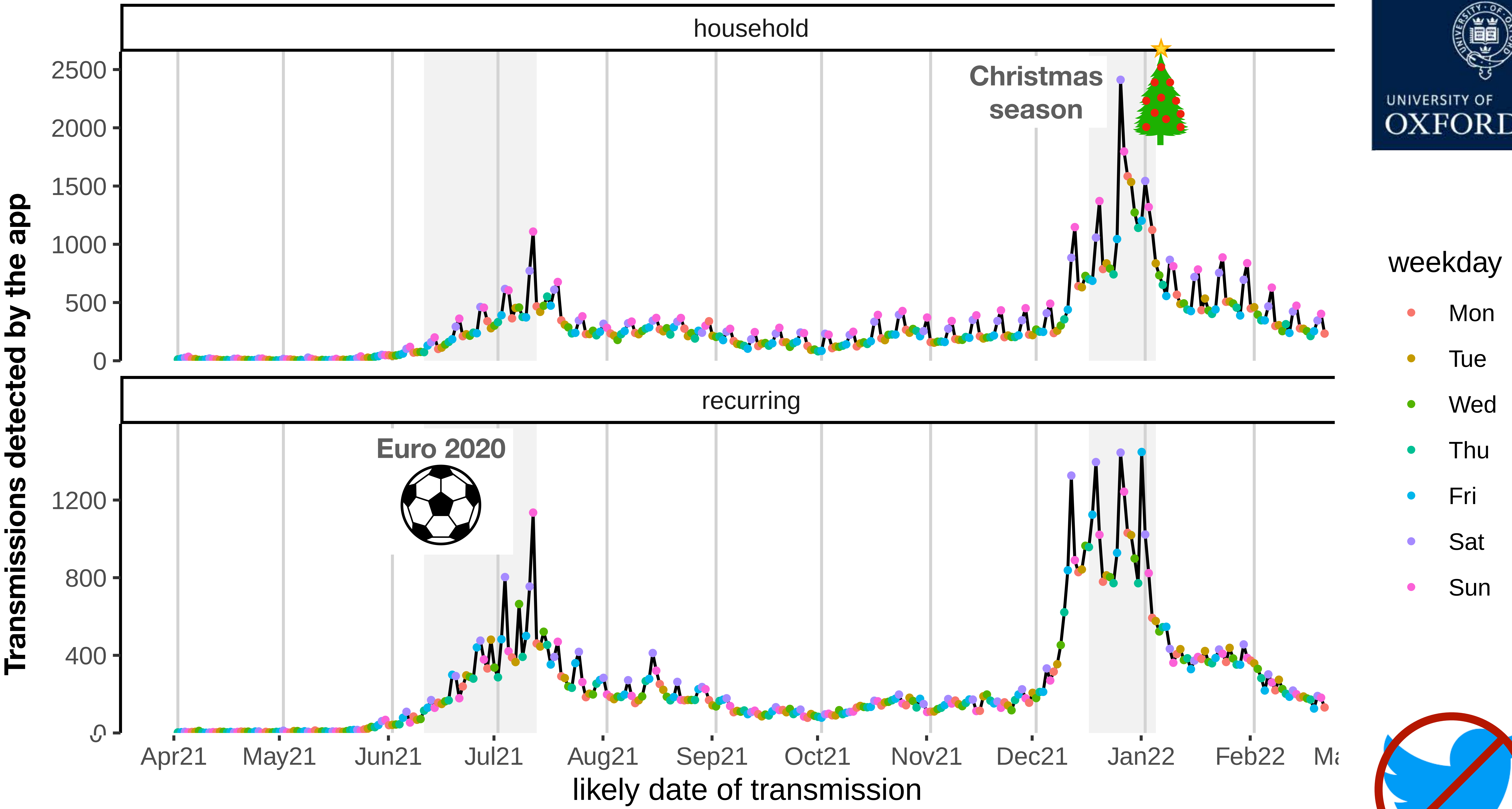
1.00
0.75
0.50
0.25
0.00
fraction
contacts
cumulative duration
cumulative risk
transmissions
type of exposure
household
recurring
single day
fleeting

Precision epidemiology: disentangling the contributions to Rt

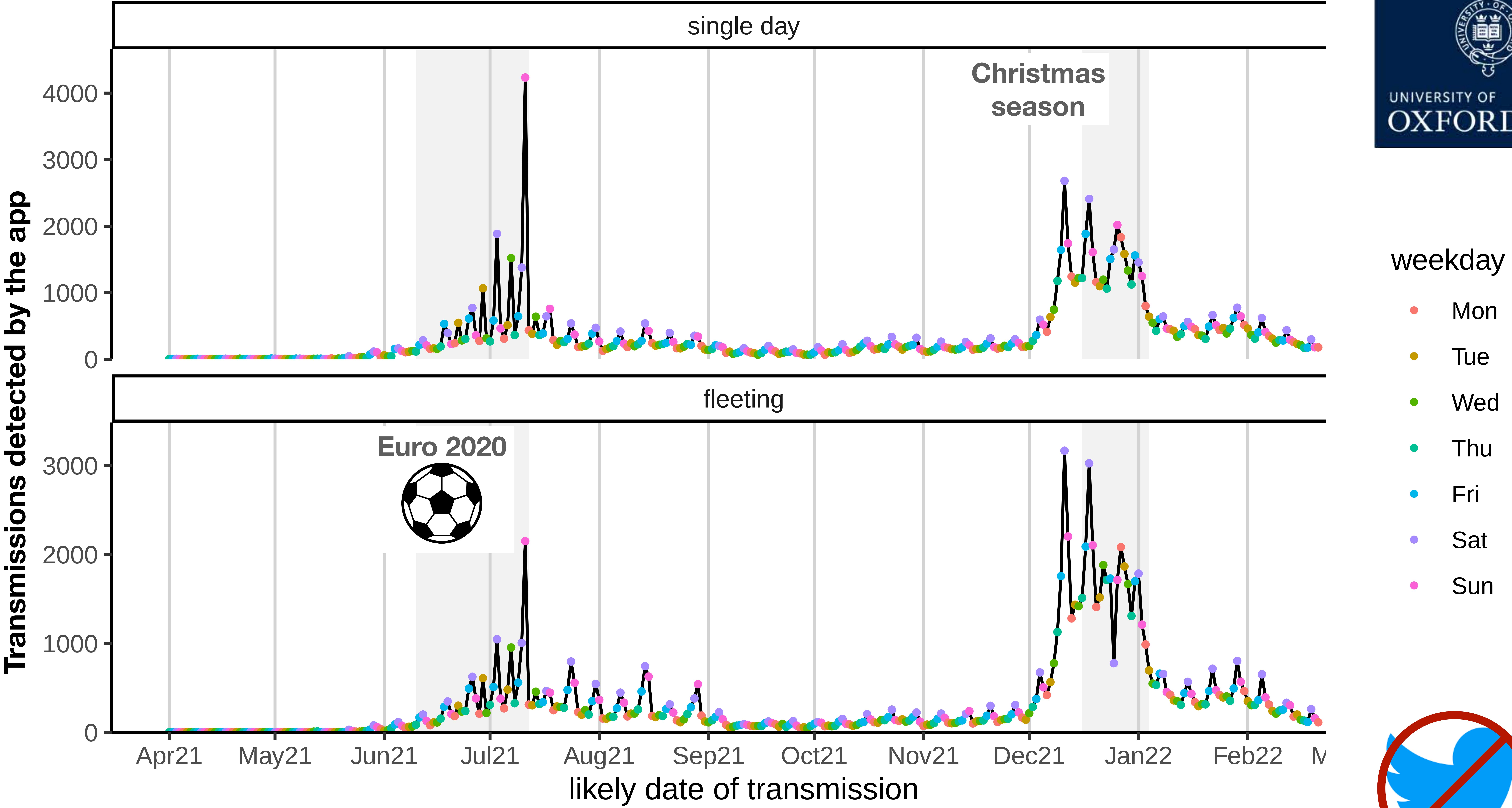


Rt = number of contacts x probability of transmission (secondary attack rate)

proximity x duration
and other physical, biological, immunological & behavioural components



Luca Ferretti, Pandemic Sciences Institute



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Summary

- Digital contact tracing is feasible & offers something unique and additional;.
- Effectiveness analysis points to substantial effect, both realised and potential (more targeted than lockdowns).
- It requires close integration with government services, and so is very political.
- Networked intervention that results in continuous direct exchange of data between neighbouring phones requires strong oversight & governance.
- Quantitative insights into transmission, 1.1% transmission per hour, 40% in households, drivers of Rt.
- Types of insights could be generated for other pathogens and disease X within weeks.

Thank you!

Thanks to NHS App team.