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.
Sept 2020 - UK

What the app does

- Trace
- Alert
- Check-in
- Symptoms
- Test
- Isolate

https://covid19.nhs.uk
Percentage of all SARS-COV-2 positive test results that were entered into the app.

UK had centralised provision and recording of SARS-COV-2 testing
Cases ~ 20.8 million

Deaths ~ 191k

Tests ~ 543 million
Uptake is heterogeneous across country. We compared 338 lower tier local health authorities in England & Wales.

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)
Theoretical basis for digital contact tracing

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:

Risk = proximity \times duration \times infectiousness

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

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:

<table>
<thead>
<tr>
<th>Exposed contact</th>
<th>Exposure window</th>
<th>Risk score / threshold</th>
<th>Proximity score</th>
<th>Duration / minutes</th>
<th>Index infectiousness</th>
<th>Exposure date</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>1</td>
<td>2</td>
<td>0.25</td>
<td>30</td>
<td>1</td>
<td>1/1/2022</td>
</tr>
<tr>
<td>$C_1$</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>30</td>
<td>1</td>
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<tr>
<td>$C_1$</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>1/1/2022</td>
</tr>
<tr>
<td>$C_2$</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>30</td>
<td>2.5</td>
<td>2/1/2022</td>
</tr>
<tr>
<td>$C_3$</td>
<td>1</td>
<td>2</td>
<td>0.25</td>
<td>30</td>
<td>1</td>
<td>1/12/2021</td>
</tr>
<tr>
<td>$C_3$</td>
<td>2</td>
<td>1.33</td>
<td>0.25</td>
<td>20</td>
<td>1</td>
<td>2/12/2021</td>
</tr>
</tbody>
</table>

Outcome data for each contact:

<table>
<thead>
<tr>
<th>Exposed contact</th>
<th>Reported positive</th>
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<tbody>
<tr>
<td>$C_1$</td>
<td>TRUE</td>
</tr>
<tr>
<td>$C_2$</td>
<td>FALSE</td>
</tr>
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<td>FALSE</td>
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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.
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Exposed contact: C₁, C₂, C₃

Reported positive: C₁ (TRUE), C₂ (FALSE), C₃ (FALSE)

Are contacts’ outcomes predicted by their exposure data?
Summarise each contact's measurements into summary metrics. e.g. here,
Max risk score = 8,
Cumulative risk score = 14,
Cumulative duration = 75 mins

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

Reported positive
- C₁ = TRUE
- C₂ = FALSE
- C₃ = FALSE
Empirical risk of infection/transmission versus app “risk score” from riskiest window

with background risk

ML background risk correction

month

- Apr/May21
- Jun21
- Jul21
- Aug21
- Sep21
- Oct21
- Nov21
- Dec21
- Jan22
- Feb22

app-measured risk: low

high
Risk of transmission from single exposure window

- Not-so-close contacts
- Close contacts

Probability of transmission (followed by positive test) per exposure window

App-measured risk score (proximity)

2m, 15min

Luca Ferretti, Pandemic Sciences Institute
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
Precision epidemiology: disentangling the contributions to $R_t$

$$R_t = \text{number of contacts} \times \text{probability of transmission (secondary attack rate)}$$

proximity $\times$ duration
and other physical, biological, immunological & behavioural components
Transmissions detected by the app

Likely date of transmission

Weekday
- Mon
- Tue
- Wed
- Thu
- Fri
- Sat
- Sun

Events:
- Christmas season
- Euro 2020
Luca Ferretti, Pandemic Sciences Institute

Transmissions detected by the app

likely date of transmission

weekdays
- Mon
- Tue
- Wed
- Thu
- Fri
- Sat
- Sun

Christmas season

Euro 2020

fleeting

single day
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.