

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

All authors contributed equally.

Correspondence: marcel.salathe@epfl.ch

Affiliations:

MS: *Digital Epidemiology Lab, Global Health Institute, School of Life Sciences, EPFL, Geneva, Switzerland*

CA: *Institute of Social and Preventive Medicine, University of Bern, Bern, Switzerland; Interfaculty Platform for Data and Computational Science (INPUT), University of Bern, Bern, Switzerland.*

NA, JR: *Institute of Social and Preventive Medicine, University of Bern, Bern, Switzerland; Division of infectious diseases, Federal Office of Public Health, Liebefeld, Switzerland*

DA, EB, JRL, WL, MP, TS, CT, MS: *School of Computer and Communication Sciences, EPFL, Switzerland*

S-IK: *Federal Office of Public Health, Liebefeld, Switzerland*

SC, DJ: *Department of Computer Science, ETH Zurich, Switzerland*

NL: *Institute of Social and Preventive Medicine, University of Bern, Bern, Switzerland*

VW: *Digital and Mobile Health Group, Epidemiology, Biostatistics & Prevention Institute, University of Zurich, Zurich, Switzerland*

TB, DM: *Epidemiology, Biostatistics & Prevention Institute, University of Zurich, Zurich, Switzerland*

EV: *Department of Health Sciences and Technology, Health Ethics and Policy Laboratory, ETH Zurich, Switzerland*

CM: *Federal Office of Information Technology, Systems and Telecommunication, Bern, Switzerland*

In the wake of the pandemic of coronavirus disease 2019 (COVID-19), contact tracing has become a key element of strategies to control the spread of severe acute respiratory syndrome coronavirus 2019 (SARS-CoV-2). Given the rapid and intense spread of SARS-CoV-2, digital contact tracing has emerged as a potential complementary tool to support containment and mitigation efforts. Early modelling studies highlighted the potential of digital contact tracing to break transmission chains, and Google and Apple subsequently developed the Exposure Notification (EN) framework, making it available to the vast majority of smartphones. A growing number of governments have launched or announced EN-based contact tracing apps, but their effectiveness remains unknown. Here, we report early findings of the digital contact tracing app deployment in Switzerland. We demonstrate proof-of-principle that digital contact tracing reaches exposed contacts, who then test positive for SARS-CoV-2. This indicates that digital contact tracing is an effective complementary tool for controlling the spread of SARS-CoV-2. Continued technical improvement and international compatibility can further increase the efficacy, particularly also across country borders.

Contact tracing is a key element of the response to the pandemic of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2019 (SARS-CoV-2). By August 30, 2020, nearly 25 million diagnosed cases and over 800,000 confirmed deaths had been recorded [1]. Contact tracing is part of a strategy of “test, trace, isolate and quarantine” (TTIQ), which aims to stop recently infected individuals from transmitting SARS-CoV-2 [2]. The capacity for transmission before the onset of symptoms and the short incubation period mean that contact tracing has to be fast to be effective [3,4]. While modelling results showed that rapid, digital contact tracing could be a critical tool for containment and mitigation efforts [5], early efforts to develop and deploy digital applications were hampered by critical limitations imposed by smartphone operating systems and concerns about confidentiality and data protection. The Exposure Notification (EN) framework, jointly developed by Google and Apple, addressed these limitations and enabled the implementation of digital contact tracing applications (apps) in which all proximity contact information, and any decision-making about whether or not to notify a user of an exposure, remain on a user’s device, rather than on the server of a central authority. This approach minimizes privacy risks [6], but the restriction of information to users’ devices means that data needed to evaluate the effectiveness of EN-based contact tracing apps have to be collected from different sources [7].

SwissCovid was the first EN-based contact tracing app launched by a governmental public health authority, initially as a pilot to a limited number of users, on May 25, 2020. On June 25, 2020 the application was made available to the general population. A growing number of governments have launched or announced EN-based contact tracing apps, but their

effectiveness remains unknown. The significance of evaluating the effectiveness of EN-based contact tracing systems was highlighted by the World Health Organization [8] and is considered an ethical requirement for the continued deployment of such systems [9]. Here, we report early findings of the SwissCovid deployment from July 23, 2020 to August 31, 2020 (hereafter referred to as the study period).

How does SwissCovid work?

The technical details of the SwissCovid system are given in [10], but briefly, SwissCovid uses the EN framework (version 1.2) to estimate proximity between phones. Each phone generates a daily Temporary Exposure Key (TEK), from which fast rotating proximity identifiers (RPI) are derived and exchanged with neighboring phones via Bluetooth Low Energy (BLE) beacons. Upon confirmation of SARS-CoV-2 infection by reverse transcriptase polymerase chain reaction (RT-PCR) testing, authorized Swiss health professionals can generate a single-use validation code (Covidcode), which is provided to the user. The Covidcode is associated with the beginning of the contagious period, which was determined to start 2 days before onset of symptoms [11] for symptomatic patients, and on the day of the test for patients who are asymptomatic at the time of testing. Upon entering a valid Covidcode in the app, TEKs for the contagious period are transmitted from the user's phone to the computer server of the Swiss Federal Office of Public Health (FOPH). All SwissCovid apps regularly contact the server for uploaded TEKs and associated data, and compute the exposure risk for the previous 10 days. To ensure privacy, notifications are shown only on the phone and are not forwarded to a server. During the study period,

the notification provided users with the last day of exposure, a reminder that they are entitled to a free RT-PCR test, and directed them to a SwissCovid-specific hotline.

The BLE beacons, used by SwissCovid to estimate whether two devices have been in close proximity to each other for a period of time, are radio signals, which attenuate with distance. The EN framework application programming interface (API) estimates the amount of time a device has been close enough to other devices of infected individuals, based on three different attenuation intervals. To identify attenuation levels that would best estimate proximity below 1.5 meters, attenuation levels for different controlled and real-life scenarios produced by different devices at different distances and orientation were measured, and subsequently corrected using the per-device calibration values provided by the EN framework. Per-device calibration values take into account varying antenna and chip characteristics that influence sending and receiving powers. These results informed the parameterization of the EN framework so that SwissCovid users are notified if they spent at least 15 minutes in close proximity (1.5 meters) to RT-PCR-confirmed cases.

Evaluation of privacy-preserving EN-based digital contact tracing

Digital contract tracing is a new method, and it is therefore crucial to rapidly evaluate and continuously monitor its effectiveness in the field. Digital contact tracing apps aim to prevent secondary transmissions by warning exposed contacts as early as possible [7]. To be an effective intervention, several technical, behavioral and procedural conditions must be met [12] (Figure 1). The app must be used by both the infected index case and exposed contacts (Figure 1, row 1), the index case must enter the Covidcode following a positive RT-

PCR test (row 2), the exposed contacts must receive notifications (row 3), and the exposed contacts must respond to the warning in a timely fashion to prevent further transmission (rows 4 and 5). These conditions cannot be assessed directly via the app, due to the voluntary and decentralized nature of the system. Alternative indicators and data sources have therefore been developed or commissioned. In Switzerland, the Federal Statistical Office (FSO) monitors downloads and active use of SwissCovid and publicly releases the relevant number on a daily basis [13,14]. The FOPH updated the clinical registration form for RT-PCR-confirmed cases before the beginning of the study period, and included the SwissCovid app as an option for the reason for the test. In addition, several ongoing research studies collect information about app usage and notifications received on a monthly basis, e.g. Corona Immunitas [15], a nationwide Sars-CoV-2 seroprevalence study with digital follow-up surveys [16], and the COVID-19 Social Monitor (<https://csm.netlify.app>), a regular, longitudinal online-survey on social, economic, and behavioral aspects related to COVID-19, drawn from a representative panel for Switzerland. Furthermore, an ongoing cohort study embedded in contact tracing in the canton of Zurich [17], which enrolls RT-PCR-confirmed cases and their close contacts, investigates circumstances of transmissions and risk exposures to SARS-CoV-2, and collects data about use of the app.

Downloads and active use of the SwissCovid app

To measure the number of app downloads and active apps, reliable monitoring is already in place (Figure 1, Box 1). By August 31, 2020, the SwissCovid app has been downloaded 2.31 million times, and the number of active apps per day has been estimated at 1.59 million

(Figure 2A). The number of active users corresponds to 18.5% of the Swiss population (8.6 million).

During the study period, the FOPH reported 8,522 confirmed SARS-CoV-2 cases. During the same time period, the FOPH issued 1,593 (18.7% of confirmed cases) Covidcodes and 1,054 (12.4% of confirmed cases, 66.2% of issued Covidcodes) of these Covidcodes were entered in the app by the users (Figure 1, Box 2; Figure 2B). While the decentralized nature makes it impossible to know how many notifications were subsequently generated, the entered Covidcodes triggered 874 phone calls to the SwissCovid hotline, thus providing evidence for actions undertaken by notified contacts (Figure 1, Box 3; Figure 2B).

The Zurich SARS-CoV-2 Cohort provides additional evidence for SwissCovid app use and notification response among RT-PCR-confirmed cases and their close contacts. From August 7, 2020 to August 28, 2020, this study recruited 96 cases out of 1227 (7.8%) individuals tested RT-PCR-positive in Zurich during the same period. Of the 96 recruited positive cases, 53 (54%) reported that they had used the SwissCovid app, of whom 48 entered the Covidcode in the app. Also, in a sample of 82 exposed close contacts of RT-PCR-confirmed cases from the same cohort, 60 of the 82 close contacts (73%) reported that they had used the SwissCovid app. Of those 60 app users, 23 (38%) received an app notification in addition to being identified by the classic contact tracing system.

Evidence for app users responding to notifications

Routine public health surveillance data suggest that notified contacts seek SARS-CoV-2 testing (Figure 1, Box 4). Information on reason for RT-PCR testing has been collected during the study period and was available for 5,491 (64%) of the 8,522 confirmed cases. Among these, 4,426 reported symptoms compatible with COVID-19, 331 reported outbreak investigation, and 26 reported the SwissCovid app as the reason for the test (Figure 1, Box 5). As the information on the reason for the test was only complete for 64% of confirmed cases, the total number of cases that were tested because of the notification by the app is likely higher. To estimate this number, we applied multiple imputation by chained equation [18], accounting for the effect of age and sex on the probability of missing information. This approach yielded a total of 37 cases (95% CI: 29-48) reporting the SwissCovid app as the reason for testing over the period considered. These cases displayed a slightly younger age distribution but a similar sex distribution compared to cases reporting another reason for testing (Figure 2C).

Effectiveness of the SwissCovid app

A key measure to quantify the effectiveness of contact tracing at identifying SARS-CoV-2 infections is the number of positive contacts per index case. This number depends on several factors, such as the number of contacts traced per index case and the overall dynamics of the epidemic. Two large studies of classic contact tracing for SARS-CoV-2 found 23 secondary cases in contacts of 100 index cases (0.23, 95% CI: 0.15-0.32) in Taiwan [19] and 2,169 positive cases in contacts of 5,706 index cases (0.38, 95% CI: 0.37-0.39) in South Korea [20]. To compare the effectiveness of the SwissCovid app to these classic contact tracing studies, we estimated the number of notified positive contacts using the

app per index case who entered a Covidcode using the formula $\epsilon = n / (c\mu)$, where $n=37$ (95% CI: 29-48) is the imputed total number of confirmed cases that reported the SwissCovid app as the reason for the test, $c=1,054$ is the number of entered Covidcodes, and $\mu=18.5\%$ is the proportion of the Swiss population that are active users of the app. Hence, the term $c\mu$ corresponds to the 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. We obtained $\epsilon=0.19$ (95% CI: 0.15-0.25), which is in a similar range to the numbers from the classic contact tracing studies.

Several factors could affect the estimated effectiveness of the SwissCovid app. Due to clustering of app users, the calculated ϵ could represent an upper estimate as the uptake of the SwissCovid app in contacts of app users might be higher than the average uptake in the Swiss population. Assuming $\mu=73\%$, which is the uptake of the app in contacts of RT-PCR-confirmed cases from the Zurich SARS-CoV-2 Cohort, we obtained $\epsilon=0.05$ (95% CI: 0.04-0.06) as a lower estimate which would still represent a respectable effectiveness of the app at identifying SARS-CoV-2 infections in contacts of index cases. However, a number of factors can also contribute to an underestimate of ϵ . First, confirmed cases might only report the presence of symptoms as the reason for the test even though they were notified by the app. Second, due to the decentralized and voluntary nature of SwissCovid, there may have been more notified contacts that got infected and self-isolated following the notification, but did not get tested, and are thus missing from the analysis. Third, reported numbers of RT-PCR-confirmed cases using the app for the study period might be slightly higher in reality due to time delays in reporting.

207
208 Reliable, continuous monitoring of app effectiveness indicators is still being improved. Also,
209 citizen reports on social media (e.g. Twitter) have suggested multi-day delays in receiving
210 Covidcodes following positive test results in some instances. Along the same lines, during
211 the study period, only about two thirds of issued Covidcodes have been entered and
212 triggered notifications (Figure 2B). Efforts to streamline procedures and app user
213 interactions with local health authorities - i.e. a direct referral of notified hotline callers to
214 the responsible local authorities - are underway. Our findings illustrate that digital contact
215 tracing can be effective even with low uptake, as suggested by mathematical modeling [21].
216 Because app coverage affects both the number of index cases and their contacts, the total
217 number of SARS-CoV-2 infections that could be identified through digital contact tracing
218 scales with the square of the coverage and could substantially increase with higher uptake
219 (Figure 2D).

220
221 In conclusion, based on the data collected during the initial deployment of the SwissCovid
222 app, we argue that voluntary digital contact tracing can show similar effectiveness at
223 identifying infected partners of index cases as classic contact tracing, provided that both
224 the index case and the exposed contacts use the app. As the effectiveness of digital contact
225 tracing crucially depends on a strong embedding into an efficient testing and contact
226 tracing infrastructure on the ground, apps like SwissCovid represent a helpful
227 complementary tool for controlling the spread of SARS-CoV-2. The strength of evidence
228 for app effectiveness as summarized in Figure 1 illustrates that most indicators have
229 reached at least a “proof-of-principle” stage. That is, the outcome of interest was observed

independently in two data sources in all important key indicators. There is, however, still room for improvement. Upcoming improvements in the EN API by Apple and Google will increase the precision in determining risk, and reduce delay in communicating it to users. International interoperability exchanges, planned for October 2020, will increase the effectiveness of the app, in particular in the countries bordering Switzerland. Speed is essential to the effectiveness of TTIQ strategies [4,5]. Reducing the time to quarantine for contacts, as a result of digital contact tracing, should provide an additional, important benefit to COVID-19 mitigation efforts.

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FIGURES

	Early signal (observed in single data source)	Proof of principle (observed in two independent data sources)	Reliable, valid quantification (regular monitoring in place)	Target reached (targets clearly defined and met by indicators)
1) Apps are downloaded and active			Box 1: Regular monitoring through Federal Statistical Office	
2) Covidcodes are issued upon PCR-positive test and entered			Box 2: Regular monitoring through Federal Statistical Office	
3) Notifications are received by exposed persons		Box 3: Reports from two independent population surveys		
4) Notifications lead to actions in exposed persons (testing, quarantine)		Box 4: Mandatory reporting upon PCR+ test		
5) Actions lead to prevention of secondary transmission		Box 5: Mandatory reporting upon PCR+ test; contact tracing study		



 Accumulation of evidence

Figure 1: Quality of evidence for SwissCovid app effectiveness. Row labels: Necessary technical, procedural and behavioral conditions for digital contact tracing to be effective. Columns: Milestones in evidence accumulation. Green boxes indicate available data sources for evidence assessments; quantitative information related to green boxes are provided in the main text.

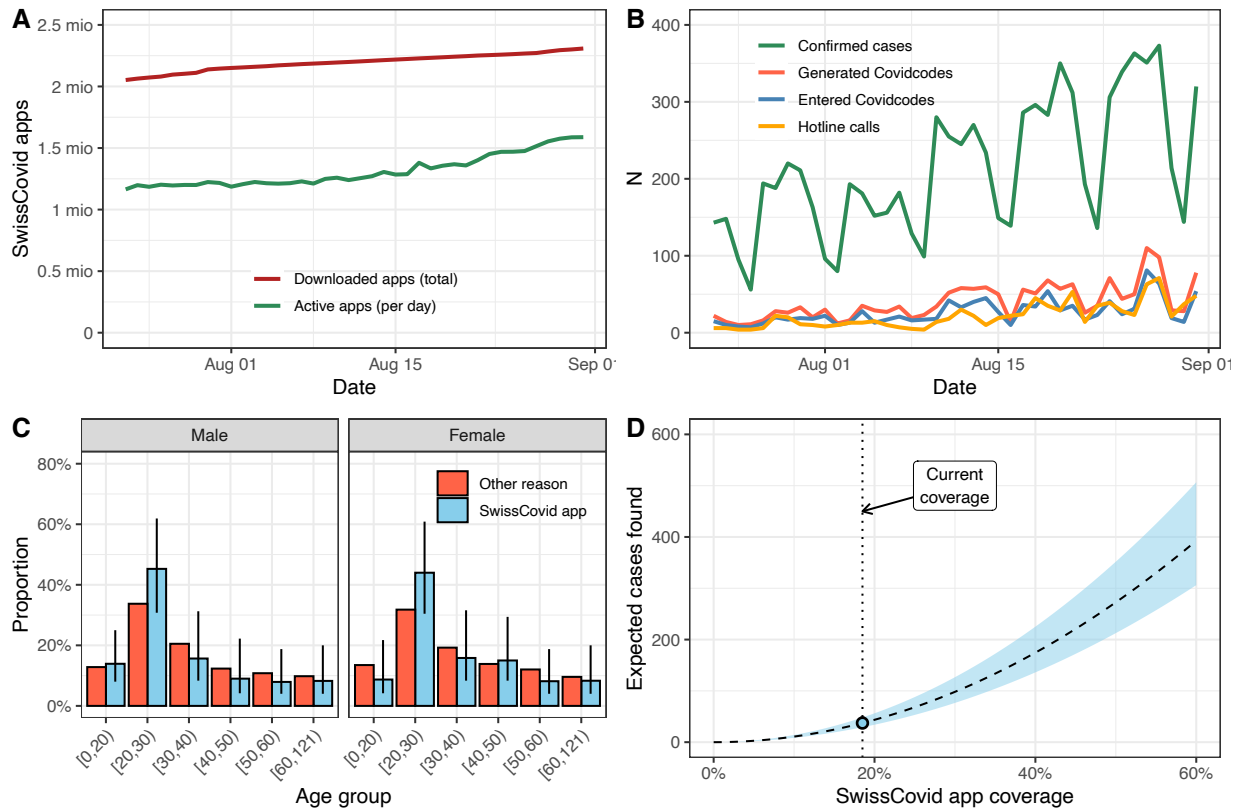


Figure 2: SwissCovid app measures. (A) Total number of downloaded apps and daily number of active apps. (B) Daily numbers of confirmed SARS-CoV-2 cases, generated Covidcodes, entered Covidcodes and hotline calls. (C) Age distribution of cases stratified by the reason for RT-PCR test (either SwissCovid app or other reason). (D) Expected number of RT-PCR-confirmed cases that were tested because of a notification by the app as a function of hypothetical app coverage during the study period. Error bars and the blue shaded area correspond to 95% confidence intervals.

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