Early Evidence of Effectiveness of Digital Contact Tracing for SARS-CoV-2 in Switzerland

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33   **In the wake of the pandemic of coronavirus disease 2019 (COVID-19), contact tracing has**

34   **become a key element of strategies to control the spread of severe acute respiratory**

35   **syndrome coronavirus 2019 (SARS-CoV-2). Given the rapid and intense spread of SARS-**

36   **CoV-2, digital contact tracing has emerged as a potential complementary tool to support**

37   **containment and mitigation efforts. Early modelling studies highlighted the potential of**

38   **digital contact tracing to break transmission chains, and Google and Apple subsequently**

39   **developed the Exposure Notification (EN) framework, making it available to the vast**

40   **majority of smartphones. A growing number of governments have launched or**

41   **announced EN-based contact tracing apps, but their effectiveness remains unknown.**

42   **Here, we report early findings of the digital contact tracing app deployment in**

43   **Switzerland. We demonstrate proof-of-principle that digital contact tracing reaches**

44   **exposed contacts, who then test positive for SARS-CoV-2. This indicates that digital**

45   **contact tracing is an effective complementary tool for controlling the spread of SARS-**

46   **CoV-2. Continued technical improvement and international compatibility can further**

47   **increase the efficacy, particularly also across country borders.**

48 Contact tracing is a key element of the response to the pandemic of coronavirus disease

49 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2019 (SARS-

50 CoV-2). By August 30, 2020, nearly 25 million diagnosed cases and over 800,000 confirmed

51 deaths had been recorded [1]. Contact tracing is part of a strategy of "test, trace, isolate

52 and quarantine" (TTIQ), which aims to stop recently infected individuals from transmitting

53 SARS-CoV-2 [2]. The capacity for transmission before the onset of symptoms and the short

54 incubation period mean that contact tracing has to be fast to be effective [3,4]. While

55 modelling results showed that rapid, digital contact tracing could be a critical tool for

56 containment and mitigation efforts [5], early efforts to develop and deploy digital

57 applications were hampered by critical limitations imposed by smartphone operating

58 systems and concerns about confidentiality and data protection. The Exposure Notification

59 (EN) framework, jointly developed by Google and Apple, addressed these limitations and

60 enabled the implementation of digital contact tracing applications (apps) in which all

61 proximity contact information, and any decision-making about whether or not to notify a

62 user of an exposure, remain on a user's device, rather than on the server of a central

63 authority. This approach minimizes privacy risks [6], but the restriction of information to

64 users' devices means that data needed to evaluate the effectiveness of EN-based contact

65 tracing apps have to be collected from different sources [7].

66

67 SwissCovid was the first EN-based contact tracing app launched by a governmental public

68 health authority, initially as a pilot to a limited number of users, on May 25, 2020. On June

69 25, 2020 the application was made available to the general population. A growing number

70 of governments have launched or announced EN-based contact tracing apps, but their

71 effectiveness remains unknown. The significance of evaluating the effectiveness of EN-

72 based contact tracing systems was highlighted by the World Health Organization [8] and is

73 considered an ethical requirement for the continued deployment of such systems [9]. Here,

74 we report early findings of the SwissCovid deployment from July 23, 2020 to August 31,

75 2020 (hereafter referred to as the study period).

76

77 **How does SwissCovid work?**

78 The technical details of the SwissCovid system are given in [10], but briefly, SwissCovid uses

79 the EN framework (version 1.2) to estimate proximity between phones. Each phone

80 generates a daily Temporary Exposure Key (TEK), from which fast rotating proximity

81 identifiers (RPI) are derived and exchanged with neighboring phones via Bluetooth Low

82 Energy (BLE) beacons. Upon confirmation of SARS-CoV-2 infection by reverse

83 transcriptase polymerase chain reaction (RT-PCR) testing, authorized Swiss health

84 professionals can generate a single-use validation code (Covidcode), which is provided to

85 the user. The Covidcode is associated with the beginning of the contagious period, which

86 was determined to start 2 days before onset of symptoms [11] for symptomatic patients,

87 and on the day of the test for patients who are asymptomatic at the time of testing. Upon

88 entering a valid Covidcode in the app, TEKs for the contagious period are transmitted from

89 the user's phone to the computer server of the Swiss Federal Office of Public Health (FOPH).

90 All SwissCovid apps regularly contact the server for uploaded TEKs and associated data,

91 and compute the exposure risk for the previous 10 days. To ensure privacy, notifications

92 are shown only on the phone and are not forwarded to a server. During the study period,

93 the notification provided users with the last day of exposure, a reminder that they are

4

94   entitled to a free RT-PCR test, and directed them to a SwissCovid-specific hotline (number

95   only shown upon notification).

96

97   The BLE beacons, used by SwissCovid to estimate whether two devices have been in close

98   proximity to each other for a period of time, are radio signals, which attenuate with

99   distance. The EN framework application programming interface (API) estimates the amount

100 of time a device has been close enough to other devices of infected individuals, based on

101 three different attenuation intervals. To identify attenuation levels that would best

102 estimate proximity below 1.5 meters, attenuation levels for different controlled and real-

103 life scenarios produced by different devices at different distances and orientation were

104 measured, and subsequently corrected using the per-device calibration values provided by

105 the EN framework. Per-device calibration values take into account varying antenna and

106 chip characteristics that influence sending and receiving powers. These results informed

107 the parameterization of the EN framework so that SwissCovid users are notified if they

108 spent at least 15 minutes in close proximity (1.5 meters) to RT-PCR-confirmed cases.

109

110 **Evaluation of privacy-preserving EN-based digital contact tracing**

111 Digital contract tracing is a new method, and it is therefore crucial to rapidly evaluate and

112 continuously monitor its effectiveness in the field. Digital contact tracing apps aim to

113 prevent secondary transmissions by warning exposed contacts as early as possible [7]. To

114 be an effective intervention, several technical, behavioral and procedural conditions must

115 be met [12] (Figure 1). The app must be used by both the infected index case and exposed

116 contacts (Figure 1, row 1), the index case must enter the Covidcode following a positive RT-

117   PCR test (row 2), the exposed contacts must receive notifications (row 3), and the exposed

118   contacts must respond to the warning in a timely fashion to prevent further transmission

119   (rows 4 and 5). These conditions cannot be assessed directly via the app, due to the

120   voluntary and decentralized nature of the system. Alternative indicators and data sources

121   have therefore been developed or commissioned. In Switzerland, the Federal Statistical

122   Office (FSO) monitors downloads and active use of SwissCovid and publicly releases the

123   relevant number on a daily basis [13,14]. The FOPH updated the clinical registration form

124   for RT-PCR-confirmed cases before the beginning of the study period, and included the

125   SwissCovid app as an option for the reason for the test. In addition, several ongoing

126   research studies collect information about app usage and notifications received on a

127   monthly basis, e.g. Corona Immunitas [15], a nationwide Sars-CoV-2 seroprevalence study

128   with   digital   follow-up   surveys   [16],   and   the   COVID-19   Social   Monitor

129   (https://csm.netlify.app), a regular, longitudinal online-survey on social, economic, and

130   behavioral aspects related to COVID-19, drawn from a representative panel for Switzerland.

131   Furthermore, an ongoing cohort study embedded in contact tracing in the canton of Zurich

132   [17], which   enrolls   RT-PCR-confirmed   cases   and   their   close   contacts,   investigates

133   circumstances of transmissions and risk exposures to SARS-CoV-2, and collects data about

134   use of the app.

135

136   **Downloads and active use of the SwissCovid app**

137   To measure the number of app downloads and active apps, reliable monitoring is already

138   in place (Figure 1, Box 1). By August 31, 2020, the SwissCovid app has been downloaded 2.31

139   million times, and the number of active apps per day has been estimated at 1.59 million

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

141   million).

142

143   During the study period, the FOPH reported 8,522 confirmed SARS-CoV-2 cases. During

144   the same time period, the FOPH issued 1,593 (18.7% of confirmed cases) Covidcodes and

145   1,054 (12.4% of confirmed cases, 66.2% of issued Covidcodes) of these Covidcodes were

146   entered in the app by the users (Figure 1, Box 2; Figure 2B). While the decentralized nature

147   makes it impossible to know how many notifications were subsequently generated, the

148   entered Covidcodes triggered 874 phone calls to the SwissCovid hotline, thus providing

149   evidence for actions undertaken by notified contacts (Figure 1, Box 3; Figure 2B).

150

151   The Zurich SARS-CoV-2 Cohort provides additional evidence for SwissCovid app use and

152   notification response among RT-PCR-confirmed cases and their close contacts. From

153   August 7, 2020 to August 28, 2020, this study recruited 96 cases out of 1227 (7.8%)

154   individuals tested RT-PCR-positive in Zurich during the same period. Of the 96 recruited

155   positive cases, 53 (54%) reported that they had used the SwissCovid app, of whom 48

156   entered the Covidcode in the app. Also, in a sample of 82 exposed close contacts of RT-

157   PCR-confirmed cases from the same cohort, 60 of the 82 close contacts (73%) reported

158   that they had used the SwissCovid app. Of those 60 app users, 23 (38%) received an app

159   notification in addition to being identified by the classic contact tracing system.

160

161   **Evidence for app users responding to notifications**

162 Routine public health surveillance data suggest that notified contacts seek SARS-CoV-2

163 testing (Figure 1, Box 4). Information on reason for RT-PCR testing has been collected

164 during the study period and was available for 5,491 (64%) of the 8,522 confirmed cases.

165 Among these, 4,426 reported symptoms compatible with COVID-19, 331 reported outbreak

166 investigation, and 26 reported the SwissCovid app as the reason for the test (Figure 1, Box

167 5). As the information on the reason for the test was only complete for 64% of confirmed

168 cases, the total number of cases that were tested because of the notification by the app is

169 likely higher. To estimate this number, we applied multiple imputation by chained equation

170 [18], accounting for the effect of age and sex on the probability of missing information. This

171 approach yielded a total of 37 cases (95% CI: 29-48) reporting the SwissCovid app as the

172 reason for testing over the period considered. These cases displayed a slightly younger age

173 distribution but a similar sex distribution compared to cases reporting another reason for

174 testing (Figure 2C).

175

176 **Effectiveness of the SwissCovid app**

177 A key measure to quantify the effectiveness of contact tracing at identifying SARS-CoV-2

178 infections is the number of positive contacts per index case. This number depends on

179 several factors, such as the number of contacts traced per index case and the overall

180 dynamics of the epidemic. Two large studies of classic contact tracing for SARS-CoV-2

181 found 23 secondary cases in contacts of 100 index cases (0.23, 95% CI: 0.15-0.32) in Taiwan

182 [19] and 2,169 positive cases in contacts of 5,706 index cases (0.38, 95% CI: 0.37-0.39) in

183 South Korea [20]. To compare the effectiveness of the SwissCovid app to these classic

184 contact tracing studies, we estimated the number of notified positive contacts using the

185   app per index case who entered a Covidcode using the formula $\varepsilon=n/(c\mu)$, where n=37 (95%

186   CI: 29-48) is the imputed total number of confirmed cases that reported the SwissCovid

187   app as the reason for the test, c=1,054 is the number of entered Covidcodes, and μ=18.5%

188   is the proportion of the Swiss population that are active users of the app. Hence, the term

189    $c\mu$ corresponds to the number of index cases entering Covidcodes scaled by the probability

190   that their contacts use the SwissCovid app assuming a homogeneous distribution of the

191   app coverage. We obtained ε=0.19 (95% CI: 0.15-0.25), which is in a similar range to the

192   numbers from the classic contact tracing studies.

193

194   Several factors could affect the estimated effectiveness of the SwissCovid app. Due to

195   clustering of app users, the calculated ε could represent an upper estimate as the uptake

196   of the SwissCovid app in contacts of app users might be higher than the average uptake in

197   the Swiss population. Assuming μ=73%, which is the uptake of the app in contacts of RT-

198   PCR-confirmed cases from the Zurich SARS-CoV-2 Cohort, we obtained ε=0.05 (95% CI:

199   0.04-0.06) as a lower estimate which would still represent a respectable effectiveness of

200   the app at identifying SARS-CoV-2 infections in contacts of index cases. However, a

201   number of factors can also contribute to an underestimate of ε. First, confirmed cases

202   might only report the presence of symptoms as the reason for the test even though they

203   were notified by the app. Second, due to the decentralized and voluntary nature of

204   SwissCovid, there may have been more notified contacts that got infected and self-isolated

205   following the notification, but did not get tested, and are thus missing from the analysis.

206   Third, reported numbers of RT-PCR-confirmed cases using the app for the study period

207   might be slightly higher in reality due to time delays in reporting.

208

209   Reliable, continuous monitoring of app effectiveness indicators is still being improved. Also,

210   citizen reports on social media (e.g. Twitter) have suggested multi-day delays in receiving

211   Covidcodes following positive test results in some instances. Along the same lines, during

212   the study period, only about two thirds of issued Covidcodes have been entered and

213   triggered notifications (Figure 2B). Efforts to streamline procedures and app user

214   interactions with local health authorities - i.e. a direct referral of notified hotline callers to

215   the responsible local authorities - are underway. Our findings illustrate that digital contact

216   tracing can be effective even with low uptake, as suggested by mathematical modeling [21].

217   Because app coverage affects both the number of index cases and their contacts, the total

218   number of SARS-CoV-2 infections that could be identified through digital contact tracing

219   scales with the square of the coverage and could substantially increase with higher uptake

220   (Figure 2D).

221

222   In conclusion, based on the data collected during the initial deployment of the SwissCovid

223   app, we argue that voluntary digital contact tracing can show similar effectiveness at

224   identifying infected partners of index cases as classic contact tracing, provided that both

225   the index case and the exposed contacts use the app. As the effectiveness of digital contact

226   tracing crucially depends on a strong embedding into an efficient testing and contact

227   tracing infrastructure on the ground, apps like SwissCovid represent a helpful

228   complementary tool for controlling the spread of SARS-CoV-2. The strength of evidence

229   for app effectiveness as summarized in Figure 1 illustrates that most indicators have

230   reached at least a "proof-of-principle" stage. That is, the outcome of interest was observed

231   independently in two data sources in all important key indicators. There is, however, still

232   room for improvement. Upcoming improvements in the EN API by Apple and Google will

233   increase the precision in determining risk, and reduce delay in communicating it to users.

234   International interoperability exchanges, planned for October 2020, will increase the

235   effectiveness of the app, in particular in the countries bordering Switzerland. Speed is

236   essential to the effectiveness of TTIQ strategies [4,5]. Reducing the time to quarantine for

237   contacts, as a result of digital contact tracing, should provide an additional, important

238   benefit to COVID-19 mitigation efforts.

239

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 →

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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.
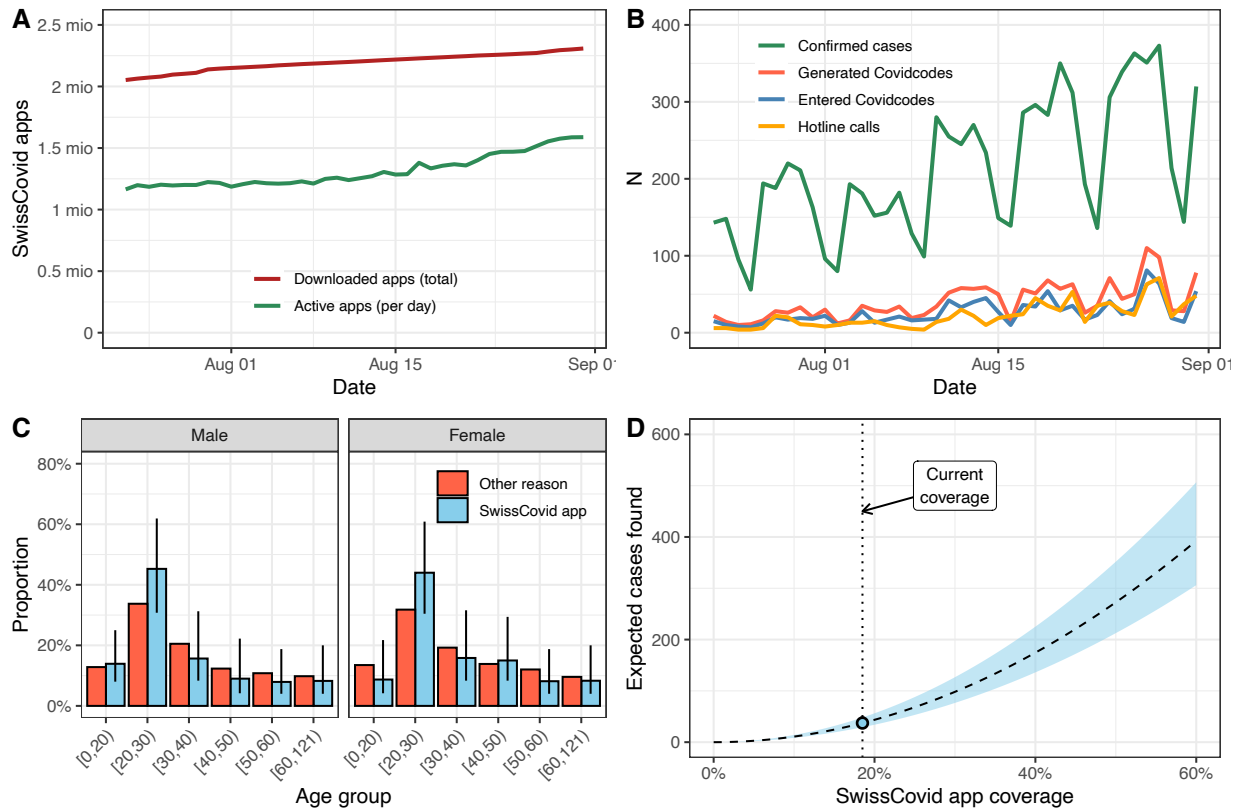
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Figure 2: SwissCovid app measures. (A) Total number of downloaded apps and daily number of active apps. (B) Daily numbers of confirmed SARS-CoV-2 cases, generated Covidcodes, entered Covidcodes and hotline calls. (C) Age distribution of cases stratified 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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