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RESEARCH ARTICLE

Performance of the Danish contact tracing smartphone application, *Smittestop* during a year of the COVID-19 pandemic

[version 1; peer review: 1 approved, 1 approved with reservations]

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Abstract

Objectives

To assess the performance of the Danish digital contact tracing (DCT) application, Smittestop, during a one-year period of the COVID-19 pandemic.

Methods

The *indicator framework for evaluating the public health effectiveness of DCT*, developed by ECDC/WHO, is used as a guideline. Observational data from four different sources is presented and used to evaluate Smittestop. The study period ranges from November 22, 2020 to November 27, 2021.

Results

By November 27, 2021, Smittestop was downloaded 2,422,756 times in a population of 5,867,412 individuals (41.0%). 23.1% of SARS-CoV-2 positive individuals reported having Smittestop. The number of

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positive test results shared on Smittestop correlated to 23.1% of all PCR-confirmed cases.

Out of 8.8 million answers to the test-indication questionnaire (34.2% of PCR-tested individuals), 117,171 reported a Smittestop-notification as their indication for testing. Of these, 1.0% (1,221) were test-positive. In comparison, 3.6% of known close contacts of infected individuals and 0.2% of individuals tested for screening purposes were positive. Extrapolations suggest that the number of identified cases would have increased substantially even with small increases in Smittestop coverage.

Conclusion

Smittestop identified cases better than mass screening, during a pre-Omicron period of the COVID-19 pandemic, but the number of identified cases is small when compared with the number of users. Improvements in the technology and higher adoption in the population could increase efficiency of Smittestop.

Plain language summary

During the COVID-19 pandemic, Denmark introduced the *Smittestop* app to help track the spread of the virus. Instead of relying on people to remember who they had close contact with, the app used Bluetooth technology to automatically detect nearby phones. It was designed with privacy in mind and didn't collect personal information. Over 2.4 million people—about 41% of the population—downloaded it.

At first, the app worked in line with national case numbers, but over time, fewer people used it to report positive tests. This may have been due to people losing interest or trust in the app. Of those who got tested after receiving a warning from the app, only 1% tested positive. This was less than close contacts, but more than in general testing. The app may have helped catch cases that manual contact tracing would have missed—like strangers on public transport.

Because the app protected users' privacy, it was hard for researchers to collect enough data to fully judge how well it worked. While *Smittestop* showed some promise, its actual impact on slowing the virus spread remains uncertain from this descriptive evaluation.

Keywords

COVID-19, SARS-CoV-2, Denmark, digital contact tracing, digital health, health apps, mobile health, mHealth, contact tracing, pandemic, surveillance



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Introduction

During various phases of the COVID-19 pandemic, particularly with the emergence of the Omicron variant, manual contact tracing faced significant challenges due to the overwhelming caseloads[1]. Additionally, manual contact tracing is limited by recall bias, since positive cases may not remember every relevant proximity they have had to another person, nor have identifiable information on all these contacts. Digital contact tracing (DCT) solutions have been suggested as a supplement or improvement to contact tracing[2], as it has been expected to notify contacts quicker and more comprehensively than manual contact tracing is able to[3,4].

These expectations led more than 50 countries[5] to develop and deploy DCT solutions during the COVID-19 pandemic, including at least 27 European countries[6]. Thus, a substantial proportion of the world's population will have had a DCT app installed on their smartphone at some point during the COVID-19 pandemic. The DCT apps were heterogeneous in many aspects, for example with regard to system architecture and the technology used. Some apps relied solely on Bluetooth, while others integrated GPS, manual contact tracing, venue QR-code scanning or other proxies for exposure, e.g., the Chinese health code system which relied on data mining in order to assign each user a risk code (green, yellow or red)[7].

Centralized DCT tools have collected data on cases and connected them to contacts in a centralized database. Due to concerns about losing public trust related to interference with privacy[8], decentralized DCT solutions relying only on Bluetooth technology were chosen by many countries, and Denmark was among the first. Decentralized apps prioritize user privacy and store little or no personal data on users, but this in turn impedes public health authorities' ability to collect data on the effectiveness of the apps and improve the technology accordingly. Details on key differences in design and technology of COVID-19 DCT tools are published elsewhere[8–10].

If DCT apps are to play a role in future epidemics, it is necessary to evaluate their performance during the COVID-19 pandemic. Several studies evaluating individual DCT solutions in different countries have been published with mixed results in terms of performance[11–22]. The aim of this paper is to evaluate the performance of Smittestop, the official and only DCT app implemented in Denmark.

Methods

Study period

The study covers the period from November 22, 2020 to November 27, 2021. This one-year period was selected because a plateau in downloads of Smittestop was reached around November 2020, and because contact tracing and test capacity remained on par with the pandemic until the arrival of the Omicron variant in the end of November 2021[23]. The stringency index in Denmark fluctuated dramatically during the study period, with lockdowns in the beginning and no restrictions in place towards the end[24]. Vaccinations were rolled out in the beginning of 2021[24]. Throughout the study period, individuals who received an alert from the *Smittestop* app were advised to book a PCR test and follow general public health recommendations. However, self-quarantine based solely on a *Smittestop* notification was not officially recommended after November 2020. In the entire study period, there was free and easy access to SARS-CoV-2 RNA PCR-tests. Denmark has been one of the countries performing the most PCR-tests per capita[25].

Materials

This study compiles data reported from several different sources as detailed below.

Smittestop: Smittestop was developed in collaboration with the Danish Ministry of Health, the Danish Patient Safety Authority and the Danish Agency for Digital Government. The app was updated according to any changing public health measures. Smittestop was decentralized, among the first apps to use the Google/Apple Exposure Notification application programming interface (API), a privacy-preserving system relying on Bluetooth within a smartphone to exchange beacons of identifiers with other Smittestop apps. It was anonymous and used no location tracking (GPS) or location tracking proxies (e.g. venue registration)[8]. For this reason, only basic information obtained from the app distributor are available for analysis: weekly number of downloads and of users who shared a positive test result[26].

Smittestop was operational from June 18, 2020 after which began an "initialization phase" where download frequency was high (see Figure 1a in the Results). Most of the changes made in the technical settings (time- and distance criteria) of the app took place in the initialization phase.

The manual contact tracing: In the study period, the Danish Patient Safety Authority (DPSA) was in contact with 95% of confirmed SARS-CoV-2 infected individuals by telephone. This includes PCR-positive individuals as well as individuals who tested positive on lateral flow tests (LFT) in public test centers[27]. Some cases interviewed by DPSA in relation to manual contact tracing were asked if they had Smittestop installed on their smartphone.

The national surveillance of COVID-19 at Statens Serum Institut (SSI): This automated surveillance system has collected information on all COVID-19 cases from different registers each day. Data on SARS-CoV-2 tests are retrieved from the Danish Microbiology Database (MiBa) and linked to data from a number of national registers. The system is described in detail elsewhere[28]. Users were only able to share positive results through Smittestop, if their positive test appeared in MiBa, and publicly available LFTs were not entered into MiBa until the beginning of 2021.

Test indication questionnaire on www.coronaprover.dk: Danish citizens used the website www.coronaprover.dk to book a time for a PCR-test[25], with a voluntary questionnaire available to indicate the reason for testing. One of the reasons

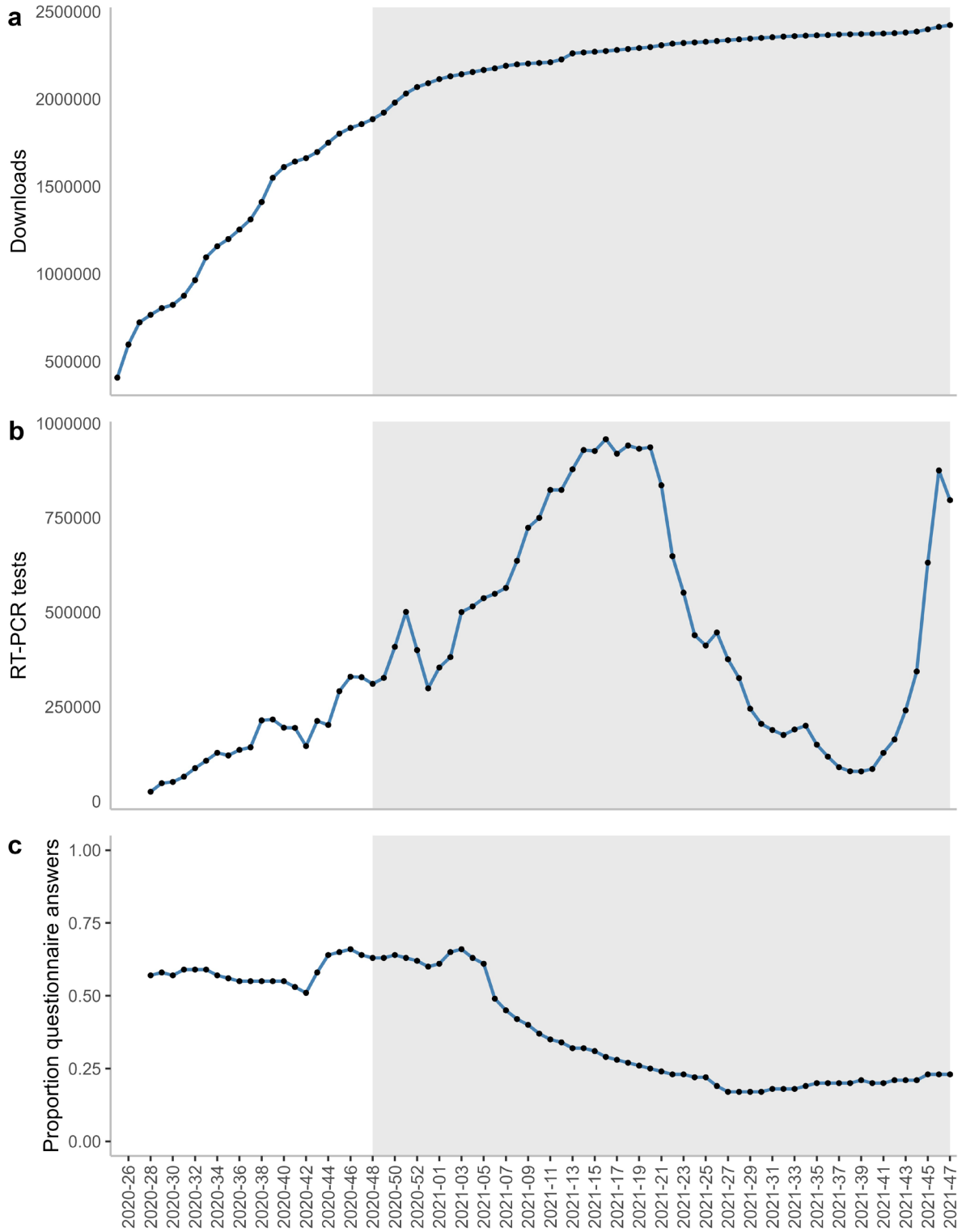

Figure 1. **1a**: Cumulated number of downloads of Smittestop since implementation in June 2020. **1b**: the number of PCR-tests for SARS-CoV-2 performed in Denmark. **1c**: the proportion of tested individuals who answered the test indication questionnaire, when booking their test on www.coronaprover.dk. Grey-shaded area marks the period analyzed in this study, x-axis shows calendar weeks.

for testing that could be selected was: "received warning from Smittestop app of potential COVID-19 exposure". Other examples were: "I have symptoms that could be of COVID-19", "my household member has COVID-19" and "I work in elderly care"[26].

Statistics Denmark[29]: was used to obtain overall figures on the Danish population.

Data analyses

The indicator framework developed by ECDC and WHO was used as a guideline for this evaluation[30]. The majority of indicators are reported excluding "time to notification" for individuals warned of exposure through the DCT tool compared to that of manual contact tracing, as these indicators were not available.

All statistical analyses of data and graphical representations were conducted using R version 4.1.3[31]. Analyses were primarily descriptive. Week 12, 2021 showed erroneous numbers from the app (see Figure 2 in the Results) and was excluded from data analyses. All other data was assumed trustworthy.

Percentage of positives and 95% confidence intervals were calculated using data from www.coronaprover.dk. The precise generation time, here defined as the interval between

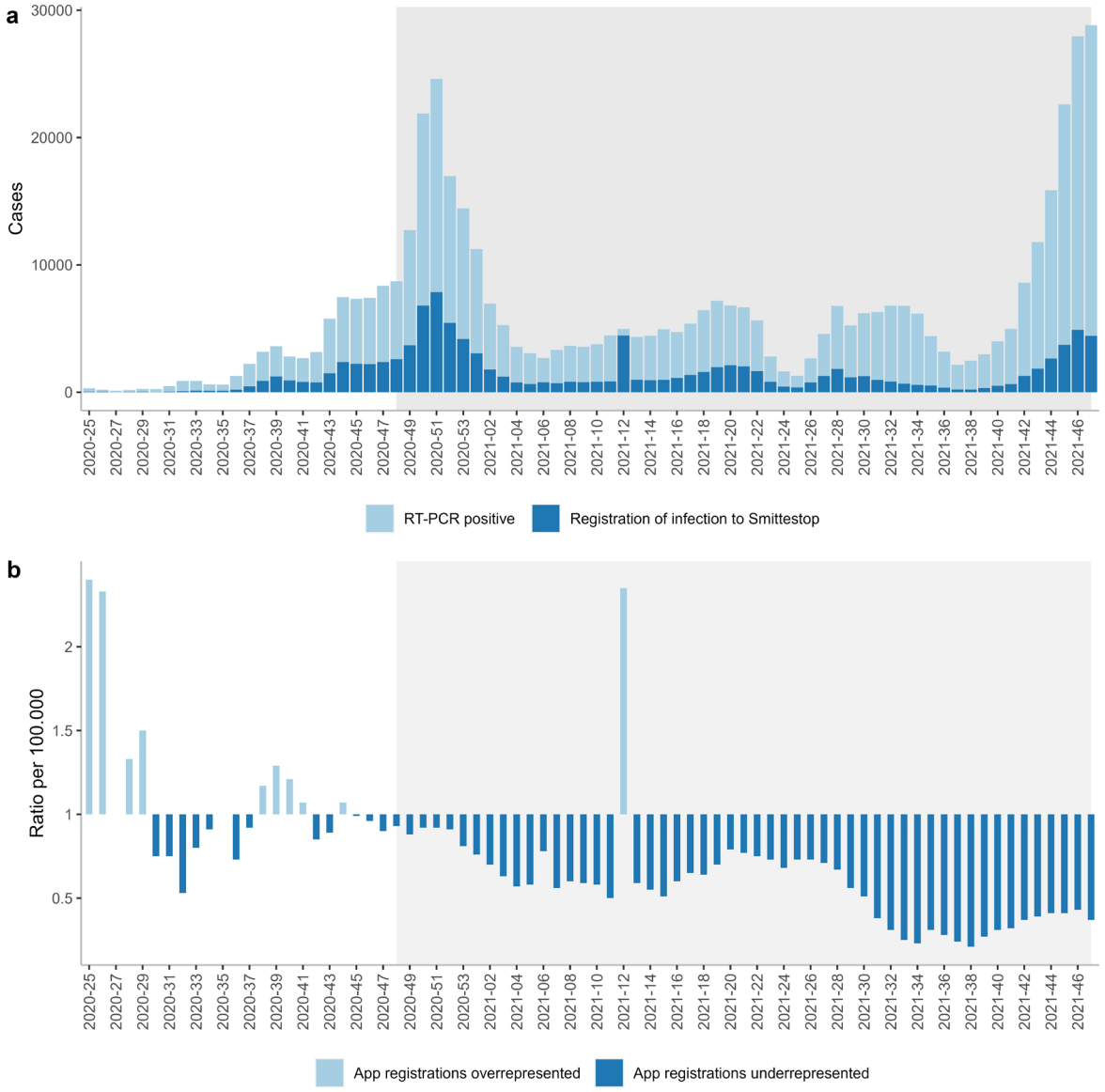

Figure 2. **2a**: Weekly number of PCR-positive SARS-CoV-2 cases and the proportion of these cases that were also registered as infected on Smittestop. **2b**: Ratio between the number of infection registrations to Smittestop per 100.000 users and the number of PCR-positive cases per 100.000 Danish inhabitants. Grey-shaded area marks the period included in this study, x-axis shows calendar weeks.

when an index person shares their positive test on Smittestop, and until notified contacts of this person present at testing services, was unknown. For simplicity, tested individuals were assumed to have received a notification from Smittestop in the same week as their test.

To estimate the number of cases that could have been identified through Smittestop if coverage had been higher, we calculated the ratio between the probability of testing positive when reporting Smittestop as the reason for being tested and the probability of answering the questionnaire when booking a test. The result of this was used as a correction factor to make extrapolations and related confidence intervals. In the extrapolations several assumptions were made: that Smittestop was uniformly distributed in the whole population, that questionnaire answers were fully representative of reasons to test, and therefore that questionnaire answers were identical to test indications in the group of tested individuals who did not answer the test-indication questionnaire.

Ethical statement

This study was conducted using data from the Danish COVID-19 surveillance as part of a task imposed on Statens Serum Institut according to Danish law (Sundhedsloven § 222). Therefore, no ethical approval was required.

Results

App downloads

Smittestop was downloaded 2,422,756 times by the end of the study period. According to Statistics Denmark, the Danish population included 5,867,412 individuals (in the 4th quarter of 2021). Assuming that every download represents one person, 41.3% (95%CI=41.3-41.3) of the Danish population had downloaded the app by the end of the study period.

Figure 1a shows, that most downloads were made shortly after implementation of the app and within the first few months thereafter. About 400,000 downloads (16.8% of all downloads completed by week 47, 2021) were made in the first week alone, and a stabilization in downloads was reached approximately a half year after implementation. Only a small fraction of the total downloads was made in 2021.

App distribution among positive cases

Among the cases interviewed by the DPSA, 85.3% were asked whether or not they had Smittestop. Of these, 23.1% reported that they had the app installed (corresponding to 19.7% of all individuals interviewed), Table 1.

There were 409,486 PCR-confirmed cases of COVID-19 in the Danish population in the study period, according to numbers from the national surveillance at SSI. Furthermore, there were 94,745 positive test shares on Smittestop. Assuming that these individuals were PCR-tested, approximately 23.1% (95%CI=23.0%-23.2%) of confirmed SARS-CoV-2 infections were entered into the app.

Table 1. Distribution in the answers from interviews of manually traced SARS-CoV-2 infected individuals in the study period to the question: "Do you have Smittestop on your smartphone?".

	Number of cases*
Yes	81,913 (19.7%)
No	272,674 (65.6%)
Undisclosed/Not asked	61,110 (14.7%)
Total	**415,697 (100%)**

**confirmed SARS-CoV-2 infected individuals (PCR-positive or positive on LFT performed in public test center)*

The pattern of positive test shares on Smittestop almost follows the pattern of confirmed infections in the population (Figure 2a). Week 12, 2021 differs significantly, which is likely due to a technical error that occurred in the app on March 26, 2021. A decline over time is observed in the ratio of infections that were shared through Smittestop (Figure 2b).

Percentage of positives

During the study period, 25.8 million tests for SARS-CoV-2 were booked through www.coronaprover.dk (Table 2). Public test activity varied during the study period, as seen in Figure 1b, some weeks just below one million individuals were tested per week (about one sixth of the Danish population) while about 100.000 tests were performed in other weeks. Willingness to answer the test indication questionnaire declined during the study period (Figure 1c), from around 60% answering the questionnaire by the end of 2020, to less than 25% over the summer of 2021.

For 8.8 million (34.2%, 95%CI=34.2-34.2) a test indication was reported in the questionnaire. 117,171 (1.3% of the 8.8 million answers) reported a Smittestop exposure notification as their test indication. The group (herein after referred to as the "Smittestop group") includes more women (60.9%) and had a mean age of 43.9 (Table 2).

Within the Smittestop group, 1,221 were SARS-CoV-2 positive resulting in a test positive rate of 1.0% (95%CI=1.0%-1.1%). This was higher than among individuals receiving PCR-tests for screening purposes (0.2%) but lower than close contacts (3.6%). Household contacts reached a 9-fold higher percentage-positive than the Smittestop group. There was no significant difference in the percentage of positives between the Smittestop group and all individuals tested (RR=1.0, 95% CI=0.9-1.1) (Table 2).

In the Smittestop group, 14.5% (n = 16,986) also specified another reason for test. In the group that specified Smittestop as the sole indication (n=100,185), 761 were

Table 2. Aggregated numbers from the test indication questionnaire on www.coronaprover.dk, the website where Danish citizens book test times for SARS-CoV-2 PCR-tests.

			Selected indications for testing (given in the questionnaire on coronaprover.dk)				
	All tests, coronaprover.dk	Test indication questionnaire answers	Symptoms that could be COVID-19	Close contact	Notification from Smittestop app	Contact in the household	Screening test (because of work/education etc.)
Number of people tested	25,841,849	8,835,256	659,244	1,387,784	117,171	223,048	2,137,800
Number of females (%)	13,927,164 (53.9%)	5,015,864 (56.8%)	402,023 (61.0%)	776,934 (56.0%)	71,375 (60.9%)	118,419 (53.1%)	1,236,492 (57.8%)
Average age in years	38	41.0	33.6	33.7	43.9	33.0	45.4
Number of positive tests	269,411	92,842	18,097	50,347	1,221	21,314	3,832
Percentage-positive [95%CI]	1.0 [1.0-1.0]	1.1 [1.0-1.1]	2.7 [2.7-2.8]	3.6 [3.6-3.7]	1.0 [1.0-1.1]	9.5 [9.4-9.6]	0.2 [0.2-0.2]
Number needed to test to find one person positive for COVID-19	96	95	36	28	96	11	558

SARS-CoV-2 positive (giving a percentage-positive = 0.8%, 95%CI=0.7%-0.8%).

Percentage of positives during different periods

The predictive power of the app was slightly lower, but not significantly (RR=0.89, 95%CI=0.72-1.11, p=0.32) during a period of high SARS-CoV-2 prevalence (winter 2020-2021) compared to a period of low prevalence (summer 2021), see Table 3. These two periods differed by SARS-CoV-2 prevalence, public health measures in place, test activity, and proportion who answered the test indication questionnaire.

Extrapolations

Table 4 shows results of extrapolations from an assumed true coverage of 23%. A further 1,970 to 3,048 cases might have been found through Smittestop, if 30% of the population had been "active users".

Discussion

In this study, we presented data collected on Smittestop in Denmark during a one-year pre-Omicron period of the COVID-19 pandemic. We aimed to assess whether Smittestop identified infectious cases accurately. Despite the predictive value seeming low (percentage-positive of 1%), some of these identified cases (761 among individuals answering the questionnaire) may represent random contacts e.g. in trains or at venues. The percentage of positives among this type of contact (0.8%), was higher than in mass screenings (0.2%). In many cases, close contacts are already told directly by the infected person, so the app's added value lies in uncovering random or unknown contacts that manual tracing might miss. This kind of extra detection could have helped reduce the spread of the virus.

We found that Smittestop was downloaded 2,422,756 times in a population of 5,867,412 individuals, indicating significant initial public interest and support for the app. To begin with, the number of positive test shares on Smittestop per 100,000 users closely mirrored the number of PCR-positive cases per 100,000 inhabitants. However, over time, there was a decline in the number of positive test shares, likely due to an increase in unused apps. Worry of high battery consumption by the app may have contributed as well as stories about technical malfunctions of the app that were shared on social media and in the public press. For example, before the end of 2020, Android devices did not receive push notifications for potential exposure; instead, users had to manually open the app to view this information. Finally, some individuals may have become tired of receiving exposure notifications and/or a general pandemic fatigue may have played a part.

Extrapolating our data, with the limitations of such crude extrapolation in mind, yielded results closer to the mathematical

Table 3. Aggregated numbers from the entire study period compared to a winter period and a summer period.
Numbers shown are: individuals tested because of Smittestop, confirmed cases and percentage of positives among these, percentage of tested individuals who answer the questionnaire overall as well as the number of Smittestop infection registrations.

Period	Confirmed cases among individuals tested because of Smittestop	Tested because of Smittestop	Percentage positive	% who answer the test indication questionnaire	Number of Smittestop infection registrations
Entire study period	1,221	117,171	1.0 [1.0-1.1]	34.1%	93,260
Winter 2020–2021 (week 48, 2020 to week 3, 2021)	646	62,439	1.0 [1.0-1.1]	63%	36,658
Summer 2021 (week 22, 2021 to week 34, 2021)	88	9,523	0.9 [0.7-1.1]	20.3%	12,678

Table 4. Illustrative extrapolations of identified cases through Smittestop if coverage had been higher than 23% (the assumed true coverage).

Coverage	Correction factor[1] [95%CI]	Cases identified through Smittesmiddle[2] n	Adjusted number of cases identified through Smittesmiddle[3] n [95%CI]	Hypothetical Increased coverage	Extrapolated number of cases that could be found[3]
23%	0.031 [0.029-0.032]	1,221	3,571 [3,377-3,776]	30%	6,076 [5,746-6,425]
				40%	10,802 [10,215-11,421]
				50%	16,877 [15,961-17,830]
				60%	24,303 [22,984-25,698]

[1]Calculated as a risk ratio of: testing positive when reporting Smittesmiddle as test indication (0.01) compared to answering the questionnaire when booking a test time (0.34).

[2]According to the test indication questionnaire on www.coronaprover.dk.

[3]Adjusted using the correction factor and related confidence intervals.

modelling studies from the early pandemic, that suggested a favorable impact of DCT on the prevention of transmission of COVID-19[3,32–34]. The number of cases identified by the app would have been substantially higher if coverage had been higher, especially if true coverage was low.

While high coverage is important, the long-term success of digital contact tracing tools depends equally, if not more, on the accuracy and usability of the technology, which are critical for retaining active users. The settings (distance- and time criteria) of the app and the technology on which it depends will influence how many and how accurately the app traces contacts. The published evaluation of the Australian COVIDsafe app, a centralized DCT tool where all DCT notifications are handled by manual contact tracers, underlined the demanding structure of this type of DCT, but also revealed situations where persons were classified as possible contacts because they had been in adjacent rooms[13]. Denmark was among the first countries to deploy a DCT app dependent on Bluetooth, thus the technology was at its infancy when Smittestop was developed and implemented, and notifications sent to contacts could have been imprecise to some degree and could not be continuously evaluated and adapted due to the high privacy requirements. Inaccurate notifications and the mentioning hereof in the media are likely to decrease adherence to usage of any DCT app. Emphasis in any future DCT systems should focus on minimizing unnecessary or inaccurate notifications.

In the event of a new pandemic with a different pathogen, Smittestop and similar DCT apps relying only on Bluetooth signals, appear, without any adjustments in the design, mainly to be able to contribute as screening tools. With the right privacy safeguards, decentralized digital contact tracing can be further adapted to address some of the main challenges

mentioned in this paper. For example, increasing the functionality of Smittestop would increase incentive to download the app and adhere to use of it. This could be done by integrating it with other public-health interventions, e.g., allowing users to book a time for a PCR-test through the app, or share a positive result of self-performed LFT-samples on the app instead of having to go to a test center. Furthermore, this would enable a positive test to automatically generate an exposure notification to contacts, giving a more comprehensive notification cascade while also alleviating the administrative burden for users. A future, alternative design of DCT apps could rely not only on anonymized positive test shares and Bluetooth beacons, but include other sources of exposure information. This could be from manual contact tracing, location-specific QR-codes, or other relevant data sources such as GPS information, given that this could be done in a privacy preserving manner. Furthermore, individuals with exposure highest risk could be given quicker access to PCR-tests, or their samples be prioritized for analysis. Future use of DCT apps could provide users with the opportunity to give differentiated consent to access different data sources and to voluntarily share more of their personal data with public health authorities. Nevertheless, the success of DCT ultimately depends on its reliability. Without a well-functioning, accurate, and user-friendly tool, even the most ambitious integration strategies are unlikely to retain users and, consequently, will struggle to deliver meaningful public health impact.

Strengths and limitations

A key strength of this study was the high testing activity in the Danish population, and the ability to derive information from conventional contact tracing authorities, as well as the system for booking PCR-tests, that enabled assessment of the test indication. These proxy measures, however, hold limitations.

Assumptions on coverage and distribution of Smittestop can lead to misinterpretations. Some individuals will have had more than one phone while others e.g. young children or technologically non-proficient individuals, will have been unable to use Smittestop (85% of Danish citizens above the age of 15 have a smartphone[35]). Also, older smartphones were initially incapable of downloading Smittestop, although a later update remedied this. Therefore, the group of capable users was smaller than the entire population, and coverage therefore higher in this group. Furthermore, "pockets" of Smittestop users could have improved app efficacy within limited demographic groups and geographical areas, and these could be poorly representative of the Danish population[36–39]. In our calculations, we made assumptions about test-indication in the proportion of tested individuals who did not fill in the test-indication questionnaire, which is an oversimplification. Furthermore, some individuals may only have specified one test indication even if they had more than one reason.

Conclusion

We found that the number of cases identified by Smittestop was relatively low when put in relation to the amount of people who downloaded the app. However, these cases could have had important roles in infection transmission during the pandemic and would not have been found as effectively by mass screenings.

This also study illustrates the challenges in assessing the effectiveness of decentralized DCT apps, given the limited data that is collected from them. In future use of DCT, public health authorities should be able to determine if the overall cost of a DCT app and the trade-off of inconvenience (and privacy) for the individual user are proportional to the public health impact achieved. This could be done by integrating the app with other public health systems, and collecting more information on possible transmission events. Without further improvements in usability, accuracy and reputation, Smittestop remains screening tools to be used as a supplement to other measures during extreme public health events such as pandemics.

Data availability

National SARS-CoV-2 surveillance data is available online, and can be downloaded as zip-files: https://www.ssi.dk/sygdomme-beredskab-og-forskning/sygdomsovervaagning/c/historiske-covid-19-opgoerelser.

Zenodo: Digital Contact Tracing Smartphone Application, Smittestop, Denmark, https://doi.org/10.5281/zenodo.16810558[39]

This project contains the following underlying data:

Smittestop_numbers.xlsx

test_indications.xlsx

Data are available under Creative Commons Attribution 4.0 International license.

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Version 1

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The core policy question that this paper is trying to address did the Smittestop app meaningfully help find COVID-19 cases that might otherwise have been missed, and under what conditions? They explicitly use the EU ECDC / WHO “indicator framework” for evaluating DCT effectiveness. This matters because DCT apps were controversial: they promised early exposure notification and quicker isolation, but many were accused of being ineffective, privacy-invasive, or both. More than 50 countries introduced DCT apps during COVID-19, including 27+ in Europe. In this respect, this paper is both a retrospective evaluation and can have policy advise for future pandemics.

The time window used for the study is 22 Nov - 27 Nov 2021. The authors triangulate data from four observational data sources: Smittestop internal metrics, manual contact tracing interviews, national COVID surveillance system, and PCR test booking portal questionnaire. The focus of the paper is on how many people downloaded the app, active use among infected people, among people who tested how many actually turned out to be COVID positives, and what could be extrapolated from the existing observations if more numbers of people in the population were actual users of the app.

The observational data analysis shows that Smittestop had some epidemiological value as it led thousands of people to get tested. Close to 1% of those tested after an app alert were actually positive - which is five times the positivity rate of routine blanket screening. Thus, it is suggestive that the app could track infections better that manual tracing would miss. But its overall, quantitative impact, as implemented, was modest. Only 23% of infected individuals actually uploaded their positive results into the app. People's engagement and compliance decayed over time. The absolute number of cases detected via app-triggered testing is quite small compared to the size of the user base and to national case totals. Higher “true coverage” and better usability could have produced substantially more detected cases.

The study cites work on centralised vs. decentralised architectures, public trust, exposure detection technologies, and ethical concerns. For example, bluetooth vs. GPS, data centralisation, user privacy and ethical concerns. They also cite works that explicitly discusses "taxonomy, ethical

challenges, and navigation aid", and papers on user attitudes, and trust in contact tracing apps. Empirical evidence from other other countries' DCT apps are also cited extensively in the paper. Multiple national evaluations, such as, NHS COVID-19 app in England/Wales (UK), Swiss notification app, Australian COVIDSafe, Finland, Italy, New South Wales, Netherlands, New Zealand QR code system etc. The study includes literature from 2022 through 2023-2024. There is some scope for including long-run, retrospective2023-2025 policy assessments of DCT in Europe that look at cost-effectiveness and proportionality. For example, retention problems over time. Studies from the Omicron phase could be cited to show whether the app usefulness changes when incidence explodes and manual tracing collapses. The paper mostly relies on pre-Omicron and early-Omicron literature. Reference to later-wave evidence, if available, may be included. The paper acknowledges that not everyone could use the app, but if there is any recent empirical evidence quantifying who was left out (elderly, low-income, migrant), they can be cited.

The paper explicitly uses the ECDC/WHO Indicator Framework for Evaluating Digital Proximity Tracing Solutions (2021). Data triangulation is appropriate for a descriptive population-level evaluation. Descriptive statistics and confidence intervals are employed as data analysis. Despite not any causal analysis, the study has academic merit within public health informatics, and pandemic-response evaluation literature.

Adding a concise methodological table aligning each measured indicator to the ECDC/WHO framework can strengthen the study's conceptual clarity and comparability. Is there a non-response bias in the coronaprover.dk questionnaire dataset that can influence positivity ratios? It may be discussed. The extrapolations in Table 4 are based on assumptions of uniform distribution, which needs qualification via a sensitivity analysis. Did the authors experience a digital divide in Denmark? Is there evidence of digital divide in other European DCT studies? A short paragraph on this can be added to the paper. Numeric correlation statistics between Smittestop positives and national case trends can provide quantitative support to Figure 2.

This paper may consider some of the above minor revisions. The paper in the present form is strong and is of index quality.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Health workforce and health labour market studies.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 26 September 2025

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Overall Assessment

The manuscript addresses an important and timely evaluation of digital contact tracing (DCT) using the Danish Smittestop app. The topic is relevant for digital health, pandemic preparedness, and public health technology assessment. The authors apply the ECDC/WHO framework and draw from multiple national data sources, which is a strength. However, there are methodological and interpretative issues that should be clarified to improve robustness and generalizability.

Concerns and recommendation

- The study relies heavily on descriptive analyses without more robust inferential or modeling methods. While understandable due to data limitations, readers may expect more sophisticated evaluation (e.g., why author scape reporting p-value).
- The conclusion that Smittestop identified cases “better than mass screening” is correct numerically, but the clinical and epidemiological impact (1% positivity, very small case numbers relative to total infections) is modest. The manuscript should balance interpretation to avoid overstating effectiveness.
- The study is context-specific (Denmark’s free PCR access, high testing capacity, and public trust dynamics). The manuscript should explicitly note limits to generalizability for countries with lower testing capacity or centralized DCT systems.
- The reliance on self-reported test indications (questionnaire) risks bias. Declining response rates over time (from 60% to <25%) further limit representativeness. This needs stronger acknowledgment.
- The “Strengths and Limitations” section could be reorganized into clearly separated bullet points for transparency.
- Reframe the conclusion to highlight limited but non-negligible contribution of the app, avoiding overstatement.
- Streamline discussion to reduce redundancy and sharpen the take-home messages.

Strengths :

- The discussion highlights added value in detecting random/unknown contact. Consider tempering or supporting with literature.
- Cross-country comparisons are mentioned, but not systematically analyzed. A clearer positioning within the wider European/global evidence base would strengthen the paper.

Good luck with the revision

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital Health

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.