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Ways to boost digital efforts to tackle the pandemic

Peter Druschel | Hannes Federrath | Marit Hansen | Thorsten Lehr
Thomas Lengauer | Michael Meyer-Hermann | Simon Munzert
Viola Priesemann | Lars Roemheld | Albrecht Schmidt
Bernhard Schölkopf | Judith Simon | Indra Spiecker gen. Döhmann
Ute Teichert | Christiane Woopen

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Editors
Dr. Johannes Fritsch, Dr. Elke Witt
German National Academy of Sciences Leopoldina
Contact: politikberatung@leopoldina.org

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1. Introduction

The pandemic can only be tackled effectively if the general population support the use of the available tools. It is paramount that in addition to following laws and observing restrictions, people take on an active role. Digital tools such as apps, tags, wearables and platforms are important ways to directly involve individuals in the fight to curb the pandemic. However, this will only be effective if they trust the tools, if the tools have been developed and are being used in keeping with the law, and if people know how to use them appropriately.

When developing, using, publicly discussing and assessing digital tools, it is therefore essential to be very clear about each tool's specific purpose. The purpose determines the contexts in which a tool is used, the data it processes, and which data protection, data security and user orientation requirements they are subject to.[1]

Digital tools are mainly used in Germany's fight against the pandemic to pursue the goals of:

(i) assisting the general populace, organizations and companies in preventing infection and in breaking the chain of infection using automated contact tracing,

(ii) assisting the public health office in its legal mandate to combat the pandemic,

(iii) researching how the virus is transmitted and spread as well as developing effective measures to get the pandemic under control.

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1 For information on the special role of transparency and comprehensibility of communication from the government and the role that voluntary use of the Corona-Warn-App plays, see the results (in German) of the online survey conducted by the "The Politics of Inequality" Excellence Cluster at the University of Konstanz: https://www.progressives-zentrum.org/wp-content/uploads/2021/05/Datenschutz-in-der-Corona-Krise_Policy-Paper-05_Dohmen-Schmelz.pdf

The different features necessary to achieve these goals cannot be easily covered by one single tool. But various tools can complement each other in terms of their impact and function. In order for a tool to be accepted by the population, it is important to clearly communicate how it works, its benefit, its risks and how the collected data will be managed. This will instil confidence in the population, which is necessary for the most comprehensive, active, and effective use of the tools.

For the time being, the use of digital tools will remain necessary even after achieving extensive immunity in the population. The risk of new waves of infection remains, due to new, more contagious, COVID-19 variants with unknown immune evasion mechanisms.[2] In addition, we still do not know how long vaccinated individuals and those who have recovered from COVID-19 will be immune for, another reason why measures to combat the pandemic cannot be lifted yet. That said, each tool should always be monitored for any changes to its risk-benefit ratio so that it is phased out if its use is no longer reasonable.

2 Wall, Wu, Harvey et al. (2021). Neutralising antibody activity against SARS-CoV-2 VOCs B. 1.617. 2 and B. 1.351 by BNT162b2 vaccination. The Lancet [Online], available at: https://doi.org/10.1016/S0140-6736(21)01290-3

2. Digital tools for largely automated contact tracing

As the COVID-19 pandemic unfolded, it became clear that airborne transmission is the primary route of infection, and that to contain the pandemic it is essential to reduce and trace people's social contacts. In an effort to lessen the dramatic impact of the government restrictions on people's lives, a number of private and government projects have been launched to develop digital contact tracing tools. These tools are intended to empower citizens to take an active role in curbing the pandemic, with the help of their digital devices, such as smartphones and other wearable electronic sensors for measuring distances (known as tags and wearables). For these tools to be accepted and widely adopted, their use needs to be voluntary and their role in combating the pandemic needs to be communicated clearly and transparently. This includes a precise definition of the purpose for which any data is used, and ongoing reviews to assess whether the tools are still needed. The objectives of the data processing must also be clearly defined and communicated, as must any changes to the way the data is used as the pandemic progresses and specific requirements emerge. At the very least, experts from data protection authorities at the regional and national levels, consumer protection bodies and civil society organisations must be able to verify that the use of these tools is appropriate and effective. These measures should also help prevent data from being stolen or misused by third parties. The debate surrounding the most suitable framework conditions for these tools has led countries around the world to adopt different concepts and promote different design principles.

For contact tracing to be effective, it must be possible for tools to store the details of a person's close contacts during a specified period, so that, in the case of infection, people detected as close contacts can be informed. Right from the outset, this begged the fundamental question of how this data would be stored. One option was a centralised solution where, for example, government bodies would store the contact data (i.e. information about any exposure that could pose a risk of infection) in a central location. The alternative was a decentralised (distributed) solution where the relevant data would be stored locally on the user's end device. In this case, if a user were to test positive for COVID-19, an ID issued from their device would trigger an exposure notification on technically equipped devices of other users who had been in contact with the infected person. The next question was whether only close exposure (i.e. proximity to other people) should be recorded, or whether it was (also) necessary to track and record the time of a person's location and movement patterns (i.e. duration and frequency of contact). In Germany and many other western countries, the answer to both these questions was that individual privacy must take precedence over more targeted data collection. Germany's Corona-Warn-App (CWA, see Section 2.1) is a decentralised solution that only records close exposure. The CWA is currently Germany's most widely used digital tool for automated contact tracing and exposure notifications for potentially infected persons. The purpose of the tool is to alert users as soon as possible that they may have been exposed to the virus and prompt them to self-isolate voluntarily, reducing the risk of transmission to others.

As the pandemic has progressed, so too has our understanding of the transmission routes for SARS-CoV-2. In particular, we have learnt that aerosol transmission is very frequent and that a large proportion of transmissions can be traced back to a smaller number of infection clusters (a process known as overdispersion). Backward contact tracing therefore has a vital role to play in combating the pandemic, since an infected person is much more likely to have been infected as part of a cluster than to be the source of a future infection cluster themselves. This observation suggests that there are benefits to recording additional time and location data, as was later introduced for the CWA with additional features for storing decentralised records of the location of contact events. Recording this data is also important for developing targeted protective measures.

In accordance with COVID-19 legislation in Germany, hospitality businesses and event organisers were required to collect contact details from their customers, such as name, address and telephone number, and to pass this data on to the relevant health authorities in the event of a positive COVID-19 case. Digital solutions have also been developed to facilitate this process of collecting data and passing it on to the authorities. One well-known app, which is used in several German states, is the so-called Luca app (see Section 3). The purpose of this app is to collect the contact details of persons that have attended a certain event or have been at a certain location. In the event of a positive COVID-19 case, this data can then be requested by the health authorities to help them identify others who may potentially be at risk.

Having discussed particular examples, it is important to note that there are numerous other digital tools that have been developed to meet these or similar requirements (see Table 1 for an overview of the technologies discussed in this paper). The principle of automation is key to making these tools as efficient as possible and providing users with an intuitive and hassle-free experience.

Table 1:
Overview of the digital tools discussed in this paper that are helping tackle the pandemic

	CWA[3]	Luca app[4]	SORMAS[5]	WEARABLES[6]	PANCAST[7]
Purpose	**Contact tracing:** Slowing rates of virus transmission by alerting users to potential exposure and prompting self-isolation and tests	**Venue check-in:** Forwarding contact details of potentially infected individuals to health authorities and notifying these individuals of the need to get tested and/or self-isolate	**Management of pandemic control measures:** Supporting health authorities in the prevention and control of infectious diseases and the early detection of outbreaks and clusters	**Distance measuring:** Tracing chains of transmission, preventing incidence of infection, warning following risk exposure and subsequent need to self-isolate/get tested, identifying high-risk exposure locations and optimising risk mitigation plans	**Contact tracing and contextual data collection (time/location):** Assessing the risk of contact in indoor environments and at mass events
IT architecture	Mobile app and central server for verifying alerts, measuring distances via Bluetooth, interface with lab test results, QR code scanner	Mobile app and central server for storing venue check-in data, QR code scanner	Desktop computer platform with database	Portable devices for distance measuring e.g. using ultra-wideband technology (UWB), light, vibration and audio alert signals, optional use of anchors for location tracking	Mobile app or dongle and central server for verifying alerts, local Bluetooth transmitter for distance measuring
Open source	Yes	Yes (proprietary)	Yes	No	Yes
Availability	App store (free for users)	App store (free for users)	Free for health authorities	Available to purchase	Not yet available
Data collection	Exposure – no contact details or location information	Encrypted location information and contact details	Contact details, infection events, location information	Contact details (partial anonymisation possible), location information	Exposure, location information
Data storage	Decentralised storage on smartphones	Centralised storage on server	Centralised storage on servers of health authorities	Centralised storage on local servers or in the cloud	Decentralised storage on user devices
Scope of access to data	Users, research teams (with users' consent)	Health authorities	Health authorities	Scope defined prior to use; usually the organisation that provides the wearables (e.g. employer or event organiser)	Users, health authorities and research teams (with users' consent)

3 https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/WarnApp/Warn_App.html

4 https://www.luca-app.de/gesundheitsamt/

5 https://www.sormas-oegd.de/hintergrund/

6 The following products and providers are listed as examples: https://kinexon.com/de/technologie/safetag; https://www.redpointpositioning.com; https://www.uwb-social-distancing.com; https://ubisense.com/contact-tracing/; https://new.siemens.com/global/en/products/automation/industrial-identification/simatic-rtls.html; https://estimote.com

7 Barthe, De Viti, Druschel et al. (2021). Listening to Bluetooth beacons for epidemic risk mitigation [Preprint]. medRxiv [Online], available at: https://www.medrxiv.org/content/10.1101/2021.01.21.21250209v1.full.pdf

As part of scientific studies, some companies (in consultation with their staff representatives) and schools have been using special sensors (known as wearables) to be worn at the workplace or school to send out alerts and track the chains of transmission between employees or pupils.[8] These wearables use ultra-wideband technology (UWB) to measure the distances between people with centimetre-level accuracy and record the duration of any contacts. If a user's proximity to another person is below the minimum defined distance for more than the designated time period, their device will trigger an alert. Contact details are also stored on a server, so that in the event of a positive test result, everybody who has potentially been exposed to the virus can be immediately notified, tested and asked to self-isolate. This, in turn, should keep the number of people that need to self-isolate to a minimum. Information about which wearable is assigned to which user is only required if a user is to be notified of their potential exposure. Data is stored specifically for this purpose for a certain time period, but otherwise individuals remain anonymous. This concept can be applied to any setting that brings people together (e.g. mass events, cultural venues, restaurants and hospitals), but it does require personal data to be collected and assigned to a specific device ID. The system can also be expanded by installing UWB anchors in rooms, which enable people's movements and contacts to be tracked in real time. This allows for hot spots, i.e. places where a particularly high number of people have potentially been exposed to the virus to be identified and risk mitigation plans to be adapted accordingly.

A decentralised approach that records exposure largely anonymously, but also automatically integrates location and other contextual information into the risk assessment, could for example be achieved using Bluetooth beacons (transmitters with no receiver functionality), which work in a similar way to the aforementioned anchors. One such solution called "Pancast" is currently being developed by multiple

8 See, for example: https://spectrum.ieee.org/tech-talk/computing/software/pro-sports-covid19-sensors-trace-rise-of-ultrawideband-tech and https://www.uni-saarland.de/lehrstuhl/lehr/forschung/saarcokids.html

Max Planck Institutes.[9] It provides for Bluetooth beacons to be installed in strategic locations (e.g. in restaurants, hairdressers, gyms and concert halls), which broadcast a signal that can be picked up by devices such as smartphones.[10] By doing this, information about the local environment (e.g. indoor/outdoor, loud talking, singing, people exercising etc.), can be factored into the calculation of the risk of transmission along with the duration of the contact. This type of system would work particularly well for large events. In this way, the reliability of exposure notifications could be improved and infection clusters could be identified (backward contact tracing, see Section 3). By installing multiple beacons in larger rooms, the accuracy of the system could even be increased.

The technology required for this solution is still being developed, but it could be combined with the existing CWA without any need to use personal data.

In the remainder of this section, we will take a closer look at Germany's CWA. Then in Section 3, we will further discuss other digital tools – like the Luca app and SORMAS – which are intended to play an important role in supporting the work of public health authorities.

2.1 The Corona-Warn-App (CWA)

Germany's CWA is a government-backed solution designed to help the general population take an active role in disrupting chains of infection.[11] Since it was first made available for download from app stores in June 2020, the app has been regularly upgraded with new features to make it more effective and increase acceptance among the population. The primary purpose of the CWA is to slow transmission rates. It does this by giving users who test positive the opportunity to warn those with whom they have been in contact of a possible exposure to the virus.

9 Barthe, De Viti, Druschel et al. (2021). Listening to Bluetooth beacons for epidemic risk mitigation [Preprint]. medRxiv [Online], available at: https://www.medrxiv.org/content/10.1101/2021.01.21.21250209v1.full.pdf

10 Advantages of this system over data collection using QR codes: more user-friendly as no need to scan the QR code, and more secure as the IDs broadcasted by the beacons change over time.

11 https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/WarnApp/Warn_App.html

Anyone who receives an exposure alert is advised to self-isolate immediately and, if necessary, be tested.

The CWA does not collect any personal data. The decentralised design – meaning that no information about exposure is stored on a central server – was deliberately chosen to maximise user confidence, IT security and data protection standards. The app uses the Bluetooth Low Energy (BLE) technology in smartphones to record the duration of any contacts where users' proximity is less than the defined maximum distance. The users' smartphones exchange rolling proximity identifiers (tokens), which are generated every 10 minutes based on a random daily key. When a user enters and confirms a positive result in the app – from either a PCR test or an official rapid test – their random device keys from the previous 14 days are released and sent to the central CWA server. All active CWA instances compare the tokens saved locally with the keys logged on the central server.[12] As soon as a match is identified, the local CWA on the user's smartphone calculates the user's individual infection risk based on factors such as length of contact and distance maintained. Users whose risk of infection exceeds a defined value then receive an exposure notification.[13]

In April 2021, a check-in feature was added to the CWA to collect additional location information and help make exposure notifications more accurate. By checking into public places such as restaurants and museums, users have access to an additional tool which can factor the increased risk of infection in indoor environments – where aerosols and droplets remain in the air and spread around the room – into its risk assessment.[14] For instance, if users have been in the same room as someone who later tests positive, the app may still issue an exposure

12 https://covid19-static.cdn-apple.com/applications/covid19/current/static/contact-tracing/pdf/ExposureNotification-CryptographySpecificationv1.2.pdf?1

13 Information on the functionality of the app can be found here: https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/WarnApp/Funktion_Detail.pdf?__blob=publicationFile

14 Lednicky, Lauzardo, Fan et al. (2020). Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. International Journal of Infectious Diseases, 100, 476-482; Klompas, Baker & Rhee (2020). Airborne transmission of SARS-CoV-2: Theoretical considerations and available evidence. Journal of the American Medical Association, 324(5), 441-442.

notification even if they had no direct contact with the infected person.[15] The check-in feature also provides users with a secure tool in line with the necessary data protection standards for checking into restaurants and similar locations.

In addition to the automated exposure notification features, other new features are gradually being added to the CWA to create added value for users. These include:

(i) a contact diary to make it easier for users, in the event that they test positive, to provide the health authorities with the necessary information for contact tracing and to start notifying their contacts themselves;

(ii) the latest daily information on infection rates across Germany;

(iii) records of negative test results, which can be shown when entering shops, restaurants and other public places; and

(iv) proof of vaccination or past infection for the same purpose.

The CWA is currently used by one in four people in Germany. Almost no other country has seen this level of uptake. Yet, despite this, the CWA currently registers fewer than one in ten contacts that are relevant for infection transmission (see Section 2.3). Although it has become evident that the uptake and use of the app to date has certainly helped slow the rate of infection in Germany, there is still vital work to be done to make the app more effective. The exposure notification process needs to become faster and more reliable, and the adoption among the population needs to be encouraged. To provide an effective and efficient system for issuing exposure notifications and prompting users to take timely action, the CWA must be widely and regularly used.

15 For information on the stability of SARS-CoV-2 viruses, see Van Doremalen, Bushmaker, Morris et al. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. New England Journal of Medicine, 382(16), 1564–1567.

2.2. Speeding up and expanding the reach of the exposure notification process

To disrupt the chain of infection, speed is of the essence: contacts of infected individuals need to be identified quickly, notified of the potential exposure and advised to self-isolate. The infectious period, which can last several days, can start just two days after infection, whereas symptoms generally only appear 5-14 days after infection. In fact, studies in other countries have shown that approximately one in two infections results from pre-symptomatic or asymptomatic persons.[16]

Any delay in the testing, reporting and exposure notification process can lead to an increase in case numbers because infected individuals can transmit the virus before showing symptoms and self-isolating.[17] One strategy currently in place to reduce, by several days, the delay caused by people waiting for a positive PCR test result – following contact with an infected person or developing symptoms – is for non-symptomatic individuals to take regular rapid tests, for instance, in schools and workplaces or before using services such as hairdressers. Results from these rapid tests can now also be entered in the CWA in an effort to speed up the exposure notification process. Although the accuracy of these tests is limited and varies depending on the manufacturer,[18] their extensive and regular use can constitute an important tool in tackling

16 He, Lau, Wu et al. (2020). Temporal dynamics in viral shedding and transmissibility of COVID-19. Nature Medicine, 26(5), 672-675; Sun, Wang, Gao et al. (2021). Transmission heterogeneities, kinetics, and controllability of SARS-CoV-2. Science, 371(6526), eabe2424; Subramanian, He & Pascual (2021). Quantifying asymptomatic infection and transmission of COVID-19 in New York City using observed cases, serology, and testing capacity. Proceedings of the National Academy of Sciences, 118(9), e2019716118; Jones, Biele, Mühlemann et al. (2021). Estimating infectiousness throughout SARS-CoV-2 infection course. Science [Online], eabi5273, available at: https://science.sciencemag.org/content/early/2021/05/24/science.abi5273

17 Currently, users of the CWA must provide consent for the laboratory to transfer their test result and also again to trigger exposure notifications in the event of a positive test result. However, since some users do not provide this consent, there are often further delays or in some cases notifications are never even sent. This problem could be solved by introducing a single option for giving more comprehensive consent when installing the app.

18 Cubas-Atienzar, Kontogianni, Edwards et al. (2021). Limit of detection in different matrices of nineteen commercially available rapid antigen tests for the detection of SARS-CoV-2 [Preprint]. medRxiv [Online], available at: https://www.medrxiv.org/content/10.1101/2021.03.19.21253950v1

the pandemic.[19] The benefits of these rapid tests can also be further enhanced by providing clear information and instructions about what to do if the test result is positive, i.e. avoid social contact, self-isolate immediately and have a PCR test taken.

Moreover, all potentially exposed individuals could be reached much more quickly if, in addition to notifying first-level contacts (i.e. the infected person's direct contacts), the CWA also notified the second-level contacts (i.e. the direct contacts' contacts) regardless of whether or not the first-level contacts had tested positive. These second-level contacts could then choose to voluntarily reduce their social contacts and get themselves tested before potentially infecting anyone else. To limit the number of people receiving an exposure notification when they are not infected, extra criteria could be added to the app's algorithm. These could include contextual factors, such as whether the contact was indoors or outdoors, the duration of the contact and whether the contact involved speaking, which could make it easier to assess the likelihood of the virus being transmitted (proactive contact tracing).[20]

2.3. Effectiveness of digital contact tracing apps

The assessment of the quantitative benefits of apps is still fraught with uncertainty, but a recently published study from the UK did conclude that an increased use of its contact tracing app, which is comparable

19 Larremore, Wilder, Lester et al. (2021). Test sensitivity is secondary to frequency and turnaround time for COVID-19 screening. Science Advances, 7(1), eabd5393.

20 Bengio, Gupta, Maharaj et al. (2020). Predicting infectiousness for proactive contact tracing. arXiv [Online], arXiv:2010.12536, available at: https://arxiv.org/abs/2010.12536. Another possibility would be to ask direct contacts who have received an exposure notification if they have experienced specific COVID-19 symptoms and use their answers to determine whether or not to send out exposure notifications to second-level contacts, rather than waiting for a PCR test to confirm an infection. Since the unrestricted triggering of anonymous notifications could serve as an attack vector for the exposure notification system, the decision to send out automatic notifications to second-level contacts is not trivial and would require significant changes to the underlying Exposure Notification Framework by Google and Apple.

to the CWA, led to a lower number of infections.[21] The effectiveness of contact tracing apps has been evaluated variedly within the research literature, with some studies based on modelling and others on empirical data.[22] What is clear, however, is that the benefit of these apps increases in accordance with the proportion of the population using them.

To increase the reach and effectiveness of the CWA, the number of users as well as people's willingness to trigger an exposure notification if they test positive needs to greatly increase. Since it was launched in June 2020, the CWA has been downloaded around 28 million times. Approximately 770,000 of Germany's 3.7 million positive test results have been forwarded on to the app by the test laboratories, and in 61 % of these cases, the user approved the release of an exposure notification.[23] This means that the CWA currently sends out an exposure notification for around one in seven registered positive COVID-19 cases. Preliminary studies have shown that – similarly to the above mentioned COVID-19 App in the UK – 87 % of CWA users that receive an exposure notification get themselves tested and around 6 % of these PCR tests have come back positive.[24] These figures confirm that exposure notifications from the CWA are taken seriously by users, but the problem remains that the only people to benefit are those who have downloaded the app and use it regularly and consistently. Current estimates suggest that this only applies to about a quarter of the population. For a contact event to be registered by the CWA, both parties must be using it; there-

21 Wymant, Ferretti, Tsallis et al. (2021). The epidemiological impact of the NHS COVID-19 App. Nature [Online], available at: https://www.nature.com/articles/s41586-021-03606-z. Like the CWA, the UK's NHS COVID-19 App also functions in a decentralized manner, although users must enter the first three characters of their postcode when they install the app. For several months now, the app has also included an option for users to make their data available for evaluation purposes. The uptake of the NHS app in the UK is (relatively) similar to the CWA in Germany.

22 López, García, Bentkowski et al. (2021). Anatomy of digital contact tracing: Role of age, transmission setting, adoption, and case detection. Science Advances, 7(15), eabd8750; Barrat, Cattuto, Kivelä et al. (2021). Effect of manual and digital contact tracing on COVID-19 outbreaks: A study on empirical contact data. Journal of The Royal Society Interface [Online], 18(178), 20201000, available at: https://royalsocietypublishing.org/doi/10.1098/rsif.2020.1000

23 Last updated: 11 June 2021. For the latest CWA usage figures, see: https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/WarnApp/Archiv_Kennzahlen/WarnApp_KennzahlenTab.html;jsessionid=AABC5B25C9671CFD7A13BA8A8C940CFD.internet101?nn=13490888

24 https://www.coronawarn.app/de/science/2021-06-15-science-blog-1

fore with uptake at just around 25 %, fewer than one in ten contacts that are relevant for transmission are currently being tracked. Generally speaking, if the proportion of people using the app were doubled, this could lead to four times the rate of recognition for high-risk exposure.

2.4. Further development and use of digital tools

Digital tools to combat the pandemic are becoming increasingly prevalent in our day-to-day lives. For this reason, we can expect to see adoption rates rise significantly in the near future. The key features will be the check-in function and the option to show test results, proof of vaccination or past infection, which could be used to grant entry to shops and restaurants. Future upgrades should ensure that the tools are as simple and user-friendly as possible, high data security standards are maintained and – as foreign travel begins to open up again – other digital solutions in use across Europe are compatible.

Ongoing updates and new features also have the potential to further increase the popularity and uptake of these tools.[25] Additional information on local case rates, local and regional COVID restrictions, test and vaccination centres, self-isolation requirements and symptom and disease progression, as well as links to useful websites, information from health authorities and details of travel and other everyday restrictions, are all features that provide practical support and added value for users. At the same time, it is vital that any new features are easy to use and accessible for all. If there are too many complex functions and operating steps (e.g. multiple steps to approve the release of test results), then people could be put off using the tools even if they are generally open to the technology. Moreover, the core functions of the apps and wearables must remain front of mind, so that neither the purpose of the tool nor the data security standards are called into question. Add-on services that would possibly request access to the user's location or pass data onto third parties should therefore be excluded.

In addition to introducing attractive new features, it is also important to communicate regularly and openly about the latest developments

25 Munzert, Selb, Gohdes et al. (2021). Tracking and promoting the usage of a COVID-19 contact tracing app. Nature Human Behaviour, 5(2), 247-255.

and continue to promote these digital tools. Alongside government efforts to provide transparent information about how apps and wearables work and what impact they can have, key public figures could support the communication strategy for increased publicity, acceptance and use of such tools. This also includes government campaigns in public institutions such as schools and other educational settings.

Conclusion:

- To improve the effectiveness of digital contact tracing tools, more efforts need to be made to raise the number of active users of these apps and wearables. This can lead to a disproportionate increase in effectiveness, particularly for app-based solutions. Making the tools more user-friendly by increasing the tangible benefits for users in their everyday lives could boost their adoption.

- In locations where the risk of exposure is higher, such as workplaces, schools, cultural institutions and large events, risk mitigation need to be urgently adapted to incorporate QR code check-in or other automated digital solutions for calculating exposure risk, using either the CWA or alternative apps and wearables. Additional government funding may be required to support this.

- The strict data protection standards, in particular those restricting the processing of personal data, must be upheld at all times.

3. Supporting public health authorities

In addition to digital tools for triggering automated exposure notifications and empowering citizens to take an active role, comparable tools are needed to assist government bodies in their legal mandate to combat the pandemic. Even though apps and wearables for automated contact tracing and exposure notifications can help slow the rate of infection, they do not directly assist the health authorities with their contact tracing work. The contact tracing process involves, among other things, identifying the contacts of an infected individual, contacting these people and advising them on what action to take. In addition, contact tracers may mandate people to go into quarantine or self-isolation to prevent the onward spread of the virus.

The current process involves a time-consuming and labour-intensive phone call with the person who has tested positive and, where necessary, an analysis of any contact lists maintained in line with the documentation requirements in the Infektionsschutzgesetz (German Protection against Infection Act, IfSG) for venues (e.g. restaurants, cinemas, concert halls and sports venues) and public transport (e.g. planes, trains and buses). For many health authorities, this workload quickly outstrips capacity when dealing with high case rates and high volumes of contacts, not least due to a lack of staff and the inadequate digital infrastructure. Digital tools are also increasingly being used to speed up the manual contact tracing process and relieve the burden on the health authorities. However, comprehensive efforts are still necessary to promote digital technologies within these organisations.

To assist its health authorities in their digital contact tracing efforts, the German government has introduced SORMAS (Surveillance Outbreak Response Management and Analysis System), a software solution that has been in use since 2014 and is constantly being refined.[26] The purpose of SORMAS is to prevent and control infectious diseases and detect outbreaks early. Germany currently only uses it to record and distribute test results for SARS-CoV-2, but other countries also use it

26 Yavlinsky, Lule, Burns et al. (2020). Mobile-based and open-source case detection and infectious disease outbreak management systems: A review. Wellcome Open Research [Online], 5, 37, available at: https://wellcomeopenresearch.org/articles/5-37

for monitoring other infectious diseases.[27] Following a series of policy decisions at the Conferences of Minister Presidents of the German federal states, SORMAS has now been installed by 90 % of local health authorities in Germany, although for various reasons – including the fact that competing technologies are already well established within some authorities – only around 50 local health authorities are currently actively using the software. If SORMAS were implemented nationwide, the whole process of managing and implementing tests, tracing contacts and overseeing self-isolation mandates could be accelerated because the local health authorities could share data directly via SORMAS and also access laboratory data using DEMIS[28], the German Electronic Reporting and Information System for Infection Prevention operated by the Robert Koch Institute (RKI). This could also help reduce data reporting delays over weekends and national holidays. Moreover, the system could deliver key data for analysing the overall course of infection, and therefore potentially improve our understanding of how cases are spread and how the pandemic can be curbed.

To support the local health authorities in their contact tracing work, additional digital tools could help identify the contacts of an infected person and make it easier to directly access their contact details. The requirements for such digital tools are very different to the CWA, since they need to identify specific individuals. The health authorities' requirements are two-fold: they need help identifying any contacts that have potentially been exposed to the virus as well as access to these people's contact details so they can notify them.

Of the apps that were developed for the purpose of recording and tracing contacts and are currently available to the general public in Germany, the Luca app is the most well-known and widely used app[29]. The majority of Germany's federal states have acquired annual licences

27 https://www.sormas-oegd.de/hintergrund/; Tom-Aba, Toikkanen, Glöckner et al. (2018). User evaluation indicates high quality of the Surveillance Outbreak Response Management and Analysis System (SORMAS) after field deployment in Nigeria in 2015 and 2018, in: Hübner, Sax, Prokosch et al. (eds.), German medical data sciences: A learning healthcare system (p. 233–237), Amsterdam.

28 For further information, see: https://www.rki.de/DE/Content/Infekt/IfSG/DEMIS/DEMIS_node.html

29 For further information about the Luca app, see: https://www.luca-app.de/gesundheitsamt/

for the system. The system records the contact details of everyone that checks in to a particular event or venue and stores this data centrally. In the event that someone tests positive, the relevant health authorities can use the system to access the contact details of everyone who was checked in to the same venue at the same time as the infected person. Access to this data must be authorised by the person using the app. Using SORMAS, it is possible to directly import and process data through an interface. However, the Luca app has no distance measuring function and has come under public criticism for the gaps in its data protection system, its potential for misuse, for data fraud and security risks it poses for the health authorities and the fact that its contact records are open to manipulation, as well as for its wider plans for commercial uses (including post-pandemic uses).[30] Moreover, few conclusions regarding the risk of infection can be made on the mere basis that two people were checked into the same venue or large event (e.g. a museum, zoo or furniture store) at the same time.

In the case of an exponential rise in infection numbers during a pandemic, any primarily manual contact tracing process will reach its limits, no matter how well staffed it is. For this reason, digital tools are needed to support the system, either in the form of one or multiple apps for personalised contact tracing and/or generating electronic venue check-in lists. The different tools absolutely must be interoperable, so that data can be collected efficiently and passed onto the health authorities.[31]

The latest data suggests that the use of apps and wearables that measure the distance between contacts and the duration of any exposure could prove to be even more effective. However, to capitalise on this, usage rates for these tools would have to be significantly reduced (see Section 2.3). The Bluetooth beacons mentioned previously are a potentially useful add-on to these tools as an alternative to printed QR codes.

30 Statement from the Chaos Computer Club, available at: https://www.ccc.de/en/updates/2021/luca-app-ccc-fordert-bundesnotbremse; Statement from leading experts in IT security, available at: https://digikoletter.github.io/

31 See also the „Wir für Digitalisierung“ (Friends of digitalisation) initiative at: https://www.wirfuerdigitalisierung.de

Looking ahead to future pandemics, it is also important to identify exactly what data health authorities need – in addition to phone numbers for notification purposes – to tackle the spread of infectious diseases. Additional information about the infected person, location and context could all improve estimates about the risk of transmission and help identify infection clusters. It is now up to science and the Robert Koch Institute – as the responsible German government agency – in cooperation with the public health authorities to work together to define what data is needed and set out plans for suitable software solutions and interoperable standards.

Alternatively, some countries in Asia have adopted what is known as a cluster strategy, where the person who initially passed on the infection is identified (backward contact tracing) in order to isolate any further persons with whom they had contact. This process is very labour-intensive and is sometimes questionable in regard to personal freedoms when credit card information, footage from surveillance cameras and information from social media is used for tracing purposes. Nonetheless, the lower case rates in countries such as Japan, South Korea and Taiwan are evidence that this approach does work.[32] Just as in the case of forward contact tracing, the key is to ensure that clusters are identified and isolated quickly.[33]

Conclusion:

- There is an urgent need to fast-track the use of digital technologies and automated contact tracing within health authorities. This requires equipping these authorities with the relevant technologies, standardising the interfaces between the different software systems, establishing interoperability standards and also staff training.

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32 Kojaku, Hébert-Dufresne, Mones et al. (2021). The effectiveness of backward contact tracing in networks. Nature Physics, 17(5), 652-658; Bradshaw, Alley, Hugginset et al. (2021). Bidirectional contact tracing could dramatically improve COVID-19 control. Nature Communications, 12(1), 1-9; Lewis (2020). Why many countries failed at COVID contact-tracing, but some got it right. Nature, 588(7838), 384-387; Müller & Kretzschmar (2021). Forward thinking on backward tracing. Nature Physics, 17(5), 555–556.

33 Kretzschmar, Rozhnova, Bootsma et al. (2020). Impact of delays on effectiveness of contact tracing strategies for COVID-19: A modelling study. The Lancet Public Health, 5(8), e452-e459; Contreras, Dehning, Loidolt et al. (2021). The challenges of containing SARS-CoV-2 via test-trace-and-isolate. Nature Communications, 12, 378.

- To improve estimates of the risk of infection and thus the ability to tackle this and future pandemics more efficiently, it is necessary to define what relevant data the health authorities need to collect and to make adjustments as new findings emerge over the course of the pandemic.

4. Collection of epidemiological data on the spread of infection for the purposes of targeted pandemic research

In addition to collecting data for the purposes of public healthcare provision and contact tracing, including the prompt distribution of automated exposure notifications, data collection is also important for gathering epidemiological information on the spread of infection. Epidemiological data can contribute important findings regarding typical transmission routes and situations, which in turn facilitates the design of future effective measures. Alongside statistics such as incidence, case numbers and mortality rates, it is also essential to acquire information about under-reporting, dominant virus variants, age distribution, hospitalisation rates and the proportion of people with previous infection and those who are vaccinated.

Research requires high-quality, representative data. There are strict protocols for collecting data as part of controlled research studies, in order to ensure data is comparable and reproducible and to maintain high research standards. Below, key types of data from different data sources are presented as they relate to various research questions.

Regular representative sampling using COVID-19 tests could use sequencing data following a positive test result to better assess the spread (and characteristics) of the different virus variants and more accurately evaluate the levels of under-reporting in different age groups. Moreover, it would be possible to compare these results with data from non-randomised studies. For instance, in the United Kingdom, COVID-19 test samples are collected from up to 100,000 randomly selected people every week. These are analysed and used as the basis for scientific research and short-term political decision-making.[34]

34 See also the COVID-19 Infection Survey, available at: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/methodologies/covid19infectionsurveypilotmethodsandfurtherinformation, and the REACT-1 studies, available at: https://www.gov.uk/government/collections/monthly-results-for-react-1-studies

To investigate specific epidemiological questions, personal data needs to be collected, centrally stored and analysed within controlled studies. Since epidemiological dynamics are always dependent on the behaviour of the population, collecting such data is of significant scientific interest. Studies of this kind can also help identify (as alluded to in Section 3) the data required by health authorities, in addition to contact details, in order to tackle this and future pandemics. Apps developed specifically for research purposes, with targeted data collection features, have an important role to play in identifying specific locations and environmental factors associated with higher contact levels and case numbers. For instance, researchers might be interested in collecting information about people's professions, living situations and socio-economic backgrounds. Data protection legislation permits the collection and processing of data for these purposes, provided that the required consent is obtained. To ensure data can be collected from a representative sample, there is also the option to impose specific legal conditions on the way researchers use this data, including appropriate personal data protection guarantees.

Another area of research is concerned with the way that digital tools are used in practice. To this end, users of the CWA already have the option to release data voluntarily (or 'donate data' as it is sometimes termed) and take part in online surveys.[35] Both features provide a feedback mechanism which shows how effective the app is in tackling the pandemic and how it could be improved. Based on this voluntary data, communication about the app can be tailored more specifically to different target groups, the risk calculation algorithm can be improved and users can be given a more targeted set of restrictions following receipt of an exposure notification. This data also provides researchers with access to a sample of people who have tested positive, differentiated for example by age, religion, vaccination status and risk profile.

To more effectively evaluate the way tools are used by the population, it would be desirable to collect high-quality data as part of controlled studies. A meaningful approach would be to take a random representative sample of the population (based on population regis-

35 See also: https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/WarnApp/Evaluation_Privatsphaere.pdf?__blob=publicationFile

ters) and then measure their behaviour as users, since this allows a representative picture for the whole population regarding the barriers to take-up and use.[36] In the end, this data could be helpful in evaluating the effectiveness of different communication strategies in promoting digital tools among different sections of the population.

Another key area is mobility and GPS data. These data types have already proven effective in demonstrating the correlation between increased mobility and social contact – e.g. as lockdown restrictions are eased – and increased infection rates.[37] What is still disputed among the scientific community, however, is the role of mobility and GPS data in tracing specific chains of transmission, e.g. in specific locations. One reason for this is the poor location tracking capability in indoor environments. The other is that a user's GPS coordinates provide no information about the specific environmental conditions in any given place and must therefore always be used in conjunction with other data (e.g. indoor/outdoor setting, ventilation, crowded environment). More accurate location data can be obtained using technology such as ultra-wideband technology, as discussed previously. This technology can be used in indoor environments to track people's movements and the distances between them and identify critical contact events with centimetre-level accuracy, both in real-time and over a period of time.

Finally, it is worth considering studies currently being carried out in Modellregionen (model regions) and at Modellprojekte (model projects) to investigate the impact of the easing of COVID-19 restrictions. To enable an analysis in line with scientific standards, the scientific community needs to be involved in designing the studies right from the very start. For instance, for the findings to be scientifically relevant, the model regions must be of sufficient size. Ideally there should also

36 Schnell & Smid (2020). Methodological problems and solutions in sampling for epidemiological COVID-19 research. Survey Research Methods, 14(2), 123–129; Schnell, Smid, Müller-Peters et al. (2020). Random samples for COVID-19 research, available at: https://www.marktforschung.de/fileadmin/user_upload/Dokumente/Schnell_Smid_Mueller-Peters_Stichprobenkonzept_COVID.pdf

37 Rüdiger, Konigorski, Edelman et al. (2020). The SARS-CoV-2 effective reproduction rate has a high correlation with a contact index derived from large-scale individual location data using GPS-enabled mobile phones in Germany. medRxiv [Online], available at: https://www.medrxiv.org/content/10.1101/2020.10.02.20188136v2; Chang, Pierson, Koh et al. (2020). Mobility network models of COVID-19 explain inequities and inform reopening. Nature, 589(7840), 82-87.

be studies comparing the impact of comparable lifting restrictions in different regions and/or randomised studies looking at the effect of different strategies. Unfortunately, however, very few of the studies conducted to date have sought consistent and systematic input from the scientific community.

Conclusion:

- Data collected for the purposes of contact tracing and other measures in tackling the pandemic is not necessarily suitable for research purposes, since research data must meet specific criteria in terms of quality, comparability and reproducibility. This also means that data collected for the purposes of healthcare provision is of limited value to researchers.

- Tests should be collected every week from a randomised representative sample of approximately 100,000 people or households, as the basis for research projects to improve our understanding of the epidemiological developments and testing practices. Ideally this data collection process should be standardised across Europe.

- To improve our understanding of the infectivity of the virus, representative model projects should be set up, e.g. in companies or at large events, to measure the impact of key transmission factors (e.g. distance/position, ventilation and volume of speaking) and track infections. These projects would provide reliable information about transmission routes that is essential for minimising the risks and assessing the adequacy of any restrictions on social contact.

- Tools, services and processes need to be rapidly developed and expanded in line with data protection standards (including appropriate consent or legal requirements), so that personal data can be collected and analysed for the purpose of targeted scientific research.

5. Necessary logical consistency, reliability and self-restraint of government action

As we have already seen, digital tools have numerous applications and roles in the ongoing fight against the COVID-19 pandemic and against future pandemics in general. For these tools to be effective, they must be used correctly and voluntarily – which means that users trust them and understand their benefits.

When introducing government-backed digital tools in the fight against the pandemic, government bodies must ensure that these tools fulfil their intended purpose – and are used exclusively for this purpose and no other – and that they meet ethical and legal standards. Their continued further development should always be supported and applications developed with government support and in line with required data protection and IT security standards must also react to market developments. This was the case as the CWA was being developed and eventually led to the creation of a functional tool based on the concept of privacy by design. However, following its launch in the middle of 2020, opportunities were missed to strengthen public confidence in the app and to consistently promote the benefits it offers. Moreover, surveys have shown that people with little trust in the political decision-making process are much less likely to use the CWA or other commercial apps.[38]

Large sections of the population also appear to be unaware of the differences between the various apps in terms of their purpose, how they work, and their data protection and data security standards. This is partly due to insufficient communication, partly to political decision-makers' sluggishness in responding to suggestions to enhance the functionality of these apps. The scientific community can play an important role in generating and disseminating fact-based information

38 Munzert, Selb, Gohdes et al. (2021). Tracking and promoting the usage of a COVID-19 contact tracing app. Nature Human Behaviour, 5(2), 247-255; Munzert, Papoutsi & Nowak (2021). Nutzung von digitalen Tools zur Unterstützung von COVID-19-Kontaktverfolgung: Wie populär sind Corona-Warn-App und Luca-App in der dritten Pandemiewelle?, available at: https://opus4.kobv.de/opus4-hsog/frontdoor/deliver/index/docId/3830/file/20210426_covid-apps-report-final.pdf

and in developing digital services that are both secure and meet the necessary data protection standards. In the long term, it is necessary to offer education in order to promote digital skills that enable citizens to assess the opportunities and risks of digital tools and feel more empowered in our digital world.[39]

Whether digital or otherwise, all approaches to testing and contact tracing require the cooperation of the population. However, experience has shown that a considerable portion of the population does not wish to be tested, avoids contact with the authorities and does not wish to disclose their own contacts. This may be due to personal beliefs or to a host of other reasons, including the costs associated with having to self-isolate, employer expectations or a lack of health insurance, residence permit or work permit. Such a lack of cooperation makes it harder to combat the pandemic, but it can be avoided by building trust, guaranteeing consistent employee rights and financial and social support, and providing legal assurances that data will be used exclusively for the purpose of tackling the pandemic. Most importantly, data must not be used for purposes such as prosecution and the government must give legal assurances to this effect.

Another way to effectively keep the pandemic under control would be to require shops and events to offer app-based check-in facilities as an alternative to manual registration systems. The Corona Protection Ordinance for the German state of Saxony (SächsCoronaSchVO) has already taken steps in this direction.[40] There is also the potential for alternative digital tools such as wearables to be used alongside apps for this purpose. However, when introducing several different IT solutions, it is vital to ensure that the technologies are interoperable and can be combined with other contact tracing methods to ensure usage rates are high enough for contact tracing to be effective. There must always be alternatives available for people who do not own a smartphone and for those with general concerns about using contact tracing apps.

39 Kozyreva, Lorenz-Spreen, Lewandowsky et al. (2021). Public perceptions of COVID-19 digital contact tracing technologies during the pandemic in Germany [Preprint]. PsyArXiv [Online], available at: https://psyarxiv.com/3x4ru/

40 Saxon Corona Protection Ordinance of 4 May 2021, amended on 6 June 2021, available at: https://www.coronavirus.sachsen.de/download/SMS-Saechsische-Corona-Schutz-Verordnung-2021-06-10.pdf

Even with case rates falling and a growing proportion of the population vaccinated, it is important to communicate that contact tracing measures and the rules around social distancing, hygiene, masks and ventilation remain as vital as ever.[41] This is especially important as long as it is unclear how long immunity lasts after vaccination or previous infection, not everyone can be vaccinated and as long as there is still a relatively high risk of new, more infectious variants with unknown characteristics arising. Moreover, it is likely that the population's willingness to be vaccinated and efficient government vaccination programs will not be sufficient to suppress the virus completely in the long-term, meaning restrictions on social contact will continue to be required.[42]

Conclusion:

- The government needs to have a targeted and sustainable long-term strategy for the use and development of digital tools and for communicating the functions, benefits and risks of these technologies.

- The use of digital tools for checking into shops, hospitality venues and public events should be promoted across Germany for as long as the epidemic situation remains an issue of national concern.

- The consistent development of digital tools is crucial not only for the successful management of the ongoing COVID-19 pandemic but also in preparation for any future pandemic.

41 Riley, Ainslie, Eales et al. (2021). Resurgence of SARS-CoV-2: Detection by community viral surveillance. Science, 372(6545), 990–995.

42 Moore, Hill, Tildesley et al. (2021). Vaccination and non-pharmaceutical interventions for COVID-19: a mathematical modelling study. The Lancet Infectious Diseases, 21(6), 793-802; Wall, Wu, Harvey et al. (2021). Neutralising antibody activity against SARS-CoV-2 VOCs B. 1.617. 2 and B. 1.351 by BNT162b2 vaccination. The Lancet [Online], available at: https://doi.org/10.1016/S0140-6736(21)01290-3

6. Members of the working group

6.1. Authors

Prof. Dr. Peter Druschel ML	Max Planck Institute for Software Systems, Saarbrücken
Prof. Dr. Hannes Federrath	Security in Distributed Systems, University of Hamburg
Marit Hansen	State Commissioner for Data Protection Schleswig-Holstein, Kiel
Prof. Dr. Thorsten Lehr	Professor for Clinical Pharmacy, Saarland University, Saarbrücken
Prof. Dr. Thomas Lengauer ML	Max Planck Institute for Informatics, Saarbrücken
Prof. Dr. Michael Meyer-Hermann	Helmholtz Centre for Infection Research, Braunschweig
Prof. Dr. Simon Munzert	Data Science and Public Policy, Hertie School Berlin
Dr. Viola Priesemann	Max Planck Institute for Dynamics and Self-Organisation, Göttingen
Lars Roemheld	Director of AI & Data, Health Innovation Hub (hih) of the Federal Ministry of Health
Prof. Dr. Albrecht Schmidt ML	Chair of Human-Centered Ubiquitous Media, Ludwig-Maximilians-Universität München
Prof. Dr. Bernhard Schölkopf ML	Max Planck Institute for Intelligent Systems, Stuttgart/Tübingen
Prof. Dr. Judith Simon	Ethics in Information Technology, University of Hamburg
Prof. Dr. Indra Spiecker gen. Döhmann	Professor of Public Law, Information Law, Environmental Law, Legal Theory, Goethe University Frankfurt

ML – Member of the Leopoldina

Dr. Ute Teichert	Academy of Public Health, Federal Association of Physicians of German Public Health Departments
Prof. Dr. Christiane Woopen	Cologne Center for Ethics, Rights, Economics, and Social Sciences of Health and Head of the Research Unit Ethics for the Department of Medicine, University of Cologne

Dr. **Ute Teichert** heads the Academy of Public Health (AfÖG) in Düsseldorf. The AfÖG is currently involved in the project for the development, implementation and evaluation of the integrated and interconnected case and contact management system (SORMAS@DEMIS) funded by the Federal Ministry of Health.

Prof. Dr. **Christiane Woopen** is a member of the independent Data Privacy Advisory Board for Telekom. On behalf of the Bertelsmann-Foundation, she and her team prepared a report on algorithms in the healthcare sector. She is also the head/working member of multiple joint research projects about ethical issues in digital healthcare sponsored by the German Federal Ministries of Education and Research (BMBF), of Health and of Justice (BMG) and Consumer Protection (BMJV).

Prof. Dr. **Hannes Federrath** is the President of the German Informatics Society (GI). During discussions, the GI recommended decentralised, data-protection-friendly solutions for digital contact tracing. As part of his academic work, Prof. Federrath is involved in numerous joint research projects on healthcare research funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), the BMBF and by the Federal Joint Committee (G-BA).

Lars Roemheld was involved in the creation of the Corona-Warn-App. He speaks neither on behalf of the Robert Koch Institute (RKI) as developer of the CWA, nor on behalf of the development team or the German Federal Ministry of Health.

Prof. Dr. **Bernhard Schölkopf** and Prof. Dr. **Peter Druschel** work as scientific cooperating partners for the Pancast Project.

6.2. Scientific Officers

Dr. Johannes Fritsch	German National Academy of Sciences Leopoldina
Dr. Elke Witt	German National Academy of Sciences Leopoldina

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Deutsche Akademie der Naturforscher Leopoldina e. V.
– German National Academy of Sciences –

Jägerberg 1
06108 Halle (Saale)
Phone: 0049 345 472 39-867
Fax: 0049 345 472 39-919
Email: politikberatung@leopoldina.org

Berlin Offices:
Unter den Linden 42
10117 Berlin

Reinhardtstraße 14
10117 Berlin

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