Perspectives on Psychological Science
1–11

DOI: 10.1177/17456916231179365
www.psychologicalscience.org/PPS

Hits and Misses: Digital Contact Tracing in a Pandemic

Maryanne Garry[1], Rachel Zajac[2], Lorraine Hope[3], Marcel Salathé[4], Linda Levine[5], and Thomas A. Merritt[6]
[1]School of Psychology, The University of Waikato; [2]Department of Psychology, University of Otago; [3]Department of Psychology, The University of Portsmouth; [4]École Polytechnique Fédérale de Lausanne; [5]School of Social Ecology, University California, Irvine; and [6]*Daily Tech News Show*, Los Angeles, California

Abstract
Traditional contact tracing is one of the most powerful weapons people have in the battle against a pandemic, especially when vaccines do not yet exist or do not afford complete protection from infection. But the effectiveness of contact tracing hinges on its ability to find infected people quickly and obtain accurate information from them. Therefore, contact tracing inherits the challenges associated with the fallibilities of memory. Against this backdrop, digital contact tracing is the "dream scenario"—an unobtrusive, vigilant, and accurate recorder of danger that should outperform manual contact tracing on every dimension. There is reason to celebrate the success of digital contact tracing. Indeed, epidemiologists report that digital contact tracing probably reduced the incidence of COVID-19 cases by at least 25% in many countries, a feat that would have been hard to match with its manual counterpart. Yet there is also reason to speculate that digital contact tracing delivered on only a fraction of its potential because it almost completely ignored the relevant psychological science. We discuss the strengths and weaknesses of digital contact tracing, its hits and misses in the COVID-19 pandemic, and its need to be integrated with the science of human behavior.

Keywords
application, health, policy, cognition, contact tracing, COVID-19, digital contact tracing, epidemiology, memory

The well-established process of contact tracing mitigates the spread of disease by breaking chains of transmission (Porta, 2014). The ultimate goal of contact tracing is to find all the contacts of infected people during their likely "period of transmission" (Eames & Keeling, 2003; Saurabh & Prateek, 2017; Swanson et al., 2018; Thole et al., 2019). To accomplish this goal, public-health officials identify the contacts of people infected and then endeavor to isolate confirmed cases and quarantine "risky" ones.

Although the goal of contact tracing is straightforward, its successful implementation is not. Contact tracing is time-consuming, and systems are often overwhelmed when diseases spread rapidly (Gardner & Kilpatrick, 2021). Furthermore, depending on the pathogen and its mode of transmission, the definition of a contact can vary widely. For instance, in the case of a sexually transmitted disease, a contact should be easy to remember. But for respiratory diseases spread through aerosol transmission, such as COVID-19, a contact could be anyone with whom an infected person has shared "airspace"—people at a party, in the supermarket, or on the bus (R. Zhang et al., 2020).

Manual Contact Tracing Is Only as Good as People's Memories

For psychological scientists, the challenge posed by contact tracing brings to mind extensive research documenting the fragility of memory (for a review, see Schacter, 2022). As is known from that research, obtaining detailed and accurate accounts from witnesses is hard (Gabbert et al., 2015). But when it comes to COVID-19, the task is harder still: The witnessed event

Corresponding Author:
Maryanne Garry, School of Psychology, The University of Waikato
Email: maryanne.garry@waikato.ac.nz

is the transmission of an invisible virus, often at an unknown time and place. People asked to recall their activities over a likely period of transmission might have trouble accurately reporting a sequence of events, unknowingly leave out whole blocks of time, or estimate imprecisely enough to be unhelpful (Grondin, 2010; Hope et al., 2013). They might mix up days or times or details—or lie because they were somewhere they should not have been (Johnson et al., 1993; Lindsay, 2014). Finally, COVID-19 itself affects cognition: Pain interferes with performance on many cognitive tasks, and many acute illnesses or suboptimal situations impair working memory (Attridge et al., 2019; Gohar et al., 2009; Smith, 2012; for a review, see Smith, 2013). In short, contact tracers face many challenges obtaining complete and accurate information (for a review, see Garry et al., 2021).

Psychological scientists have done much to tackle parallel problems in the legal arena, developing interview protocols to maximize the completeness and accuracy of what eyewitnesses recall (Hope & Gabbert, 2019). It stands to reason these established protocols should also help with contact tracing, and initial results suggest they do. In one experimental analog, a contact-tracing protocol grounded in cognitive principles known to enhance memory increased both the number of contacts reported and the detail provided about them (Evans et al., 2022).

But real-world contact-tracing protocols largely fail to take memory challenges on board—much less adopt empirically based methods to maximize an infected person's complete and accurate recall. Take, for example, the U.S. Centers for Disease Control and Prevention's (CDC; 2022) advice to health departments, described as a "Multipronged Approach to Fight the COVID-19 Pandemic." Of the seven "core principles" in its approach, the closest the CDC gets to memory is to declare that public-health staff should "work with a patient to help them recall everyone with whom they have had close contact." Given what is known about the challenges of obtaining complete and accurate accounts from memory, this advice is ludicrously inadequate. Imagine telling trainee pilots that they should simply "work with the plane to keep it in the sky." And yet that is essentially what the CDC guidelines do—suggesting little has changed since Brewer et al. (2005) revealed much of the epidemiology literature lacks grounding in basic principles of memory.

Digital Contact Tracing

Enter digital contact tracing, which tackles many of the problems with retrieving and "extracting" memories. Not only can digital contact tracing operate faster than manual contact tracers, it also makes people's phones do some of the remembering for them.

Early in the pandemic, epidemiologists and engineers recognized that phones could be turned into powerful contact-tracing tools but had different ideas about how best to harness that power (for a review, see Anglemyer et al., 2020). In one proposed approach, users would launch an app to scan QR codes posted at "checkpoints." They could also use the app to report a positive test or to check if they had been exposed to infected people (Yasaka et al., 2020). Although the math was solid, the psychology was not: Yes, this approach would eliminate the need for people to remember their movements, but requiring people to scan location-based QR codes would instead tax prospective memory. Remembering to scan would, at first, probably be cued by the novelty of the situation and the environmental prompts. Yet as the novelty wore off and the prompts became another part of the ordinary environmental backdrop of life, cognitive demands would increase, as would failures (Einstein et al., 2005, 2018).

Other digital-contact-tracing apps circumvented these problems by capitalizing on the fact that all modern phones have built-in Bluetooth. Bluetooth was designed to connect devices to one another over the air—and although Bluetooth was not designed for contact tracing, the strength of its signal can proxy for the distance a pathogen can travel (Salathé et al., 2020). Nearby phones detect each other, automatically exchange anonymous codes, and alert each other later if an owner tests positive (Cencetti et al., 2021). In the COVID-19 pandemic, much of digital contact tracing adopted this Bluetooth-driven approach, in particular the "exposure notification" framework developed by Google and Apple (Wilson et al., 2022). Switzerland's SwissCovid app was the first to integrate this framework, between May and June 2020.

Digital Contact Tracing Was Effective

The empirical data suggest digital-contact-tracing apps reduced the incidence of COVID-19 cases in many countries (Salathé et al., 2020). A comprehensive analysis of the UK's National Health Service (NHS) app showed that for every 100 people notified, six tested positive (Wymant et al., 2021). This "yield" is not only the same as observed in manual contact tracing—but relative to manual methods, the number of contacts identified with digital contact tracing was 2.5 times higher. Moreover, one case was averted for each person who gave consent for contacts to be notified. Although only 72% gave this consent, a conservative estimate suggests 4,200 deaths were prevented in the UK during the fall wave of 2020.

In short, digital contact tracing broke more chains of infection relative to manual methods.

What is more, digital contact tracing achieved this level of success while preserving privacy. After all, these systems could quickly be abused if authorities sought access to data for purposes other than tracing contacts. But because the Apple and Google framework used a decentralized protocol that does not share contact information with a central server (the "decentralized privacy-preserving proximity" protocol; Troncoso et al., 2020), a large-scale data leak is prevented through a "privacy-by-design" approach.

Nonetheless, Digital Contact Tracing Did Not Live Up to Its Potential

Although digital contact tracing solved many of the problems associated with manual contact tracing, it was certainly not without its own. Some of these problems stemmed from the digital divide: Digital-contact-tracing apps were often dropped into public-health systems that were (and still are) deeply nondigital. As a result, almost every time apps made contact with the wider system, other problems surfaced. These problems ranged from obtaining a test to receiving timely results of that test. Although all apps using the exposure-notification framework were built on the same technical protocol, each country was left to implement its own user interface. In some locations, users were left to figure out how to adjust even the basic functions of the app. When it came to testing, the UK's NHS app was strongly integrated with results so that a positive test triggered swift alerts (Wymant et al., 2021). By contrast, the SwissCovid app was not, and local health authorities often struggled to get activation codes to COVID-positive users in an epidemiologically reasonable time.

The digital divide was also reflected in access to digital contact tracing: Some people were at heightened risk of contracting COVID-19, including older adults and people of low socioeconomic status (Patel et al., 2020; Shahid et al., 2020; Y. Zhang et al., 2021). These same people were also the people least likely to have phones and operating systems modern enough to run digital-contact-tracing apps (Bosco & Cvajner, 2021; Rizzo, 2020; Watts, 2020). In other words, the most precarious people were also systematically excluded from the benefits of digital contact tracing (Ramsetty & Adams, 2020).

Once the problems associated with the digital divide are accounted for, the rest of the problems were human behavior. Put simply, psychological science was not well integrated into digital contact tracing. This lack of integration was understandable early on when public-health officials needed to move faster than a rapidly replicating, mutating virus. But at the risk of sounding like "Monday-morning sports psychologists," an understandable oversight is not necessarily a benign one. Indeed, there has been a predictable disconnection between the capability of these digital tools and how people have reacted to them.

Ultimately, that disconnection has limited the success of digital contact tracing in at least two ways. First, the effectiveness of digital contact tracing depends not simply on the technology but also on its adoption. The public's lack of knowledge about how the apps worked, when they would be notified, and how their privacy was protected all apparently conspired to create problems (Altmann et al., 2020; Bente et al., 2021; Munzert et al., 2021). Unsurprisingly, people who reported more concerns about privacy also reported more reluctance to use a digital-contact-tracing app (Tomczyk et al., 2021; see also Prakash & Das, 2022).

Second, for a digital-contact-tracing app to be helpful, downloading it is not enough; people have to use the app. "Use" is obviously a challenge for any app, many of which are much more enticing to use than an epidemiological tool (in fact, roughly half the apps people install are used less than once a week; Google, 2016). But with digital contact tracing, success hinges on use: The more consistently people use apps, the more opportunities there are to detect risky exposures. In the last quarter of 2020, although most people in the UK had heard of the NHS app, 50% had downloaded it, and only 28% used it regularly (Wymant et al., 2021). The "app use" problem is compounded by what consent these users give. In the UK, only 72% of app users gave consent for their contacts to be notified. Although it is not known why so many people withheld consent in the UK, it is known that people withheld consent in Japan because they feared causing trouble for others (Machida et al., 2022). Low rates of adoption and consent are concerning in light of one U.S. study that showed that more than half of people with serological evidence of COVID-19 infection had no idea they had been infected, and a small number of them reported having no symptoms (Joung et al., 2022). Although this study was not about contact tracing, it seems reasonable to surmise that an alert from a digital-contact-tracing app might encourage more people like these to test and isolate.

In many respects, the success of digital contact tracing is remarkable given these obstacles to its effectiveness. While epidemiologists and engineers ponder where things went wrong on the technical side, psychological science already suggests three areas in which things went wrong with the implementation.

Reality and uncertainty

Before 2020, digital contact tracing existed as proof of concept (Danquah et al., 2019). The majority of people had never heard of it, let alone used it. But classic research applying cognitive principles to education shows that when people need to learn something new, what they understand and remember arises from "semantic context"—related information such as titles, advance goals, or illustrations that make it easier for people to partition incoming information and connect it to their prior knowledge (Ausubel, 1960; Bransford & Johnson, 1972; Mayer & Gallini, 1990; Pichert & Anderson, 1977). Consider, for example, how well people might understand, let alone recall, this passage:

> First you arrange things into different groups depending on their makeup. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step, otherwise you are pretty well set. It is important not to overdo any particular endeavor. (Bransford & Johnson, 1972, p. 722)

The passage is nearly incomprehensible, and people recall little of it later. But other people comprehend and recall roughly twice as much. How? These people were told the passage was about "washing clothes." Those two words created a semantic context that helped people process information in the moment and link it to what they already know. It seems possible, then, that one significant shortcoming in the effectiveness of digital contact tracing was that public officials did not help citizens (a) to organize information (especially correct information) about COVID-19 and (b) to link it to what they already knew. Without an understanding of how COVID-19 spread or the tactics to fight it, there is little ability to understand why digital contact tracing was a key weapon.

Did public-health officials fail to provide a helpful, widely shared semantic context for the crucial role of contact-tracing apps? There are reasons to think the answer is yes. Digital contact tracing, like most measures to control the pandemic, was implemented in a confusing landscape of competing "facts"—an incoherent semantic context (Adam, 2020; Wu et al., 2022). Public-health agencies were chief sources of this incoherence. For example, as early as March 2020, the World Health Organization declared "the virus is not airborne" (Greenhalgh et al., 2022). In many parts of the world, people were told they were safe at a specified distance (a distance that in Australia, for example, was variously described as six boomerangs, four koalas, one adult kangaroo, or a small saltwater crocodile). But the very premise of digital contact tracing, that infected people are a threat if you are merely nearby for long enough, seemed incompatible with the idea that the virus is not airborne.

In an ideal world, people would simply have accepted that scientific understanding evolves, put on a mask, and started using their contact-tracing app regularly. But some cognitive dispositions make it hard to shake early information, perhaps because people evolved to form first impressions swiftly (Schaller, 2008; Zebrowitz & Collins, 1997). Indeed, information encountered early often has an outsized influence compared with information encountered subsequently, whether about people, noise, or even a sequence of wines (Mantonakis et al., 2009; Oberfeld et al., 2018; Zebrowitz, 2017; see also Tversky & Kahneman, 1974). Furthermore, and especially in situations of uncertainty, early information (even when irrelevant) "anchors" what people think and do (Tversky & Kahneman, 1974). In the face of subsequent information, people can update and adjust away from these anchors—although often not sufficiently, presumably because the adjustment process requires effort (Epley & Gilovich, 2006). Irrelevant anchors can even create memory distortions of subsequently encountered information (Navarre et al., 2022). In short, it is hard to update.

A related problem is that the public's trust in science is notoriously lower than researchers would like—especially when messages from scientists conflict with one another or change over time. A Pew survey conducted before the pandemic suggested a third of Americans did not understand that scientific knowledge is continually updated and believed the scientific method can be "manipulated" to produce specific results (Funk et al., 2019). This problem is not unique to Americans: In late 2020, 41% of Germans agreed that scientists did not tell people "everything they know about the coronavirus" (Bromme et al., 2022). These beliefs fit with the idea that political populism has infected science. Scientific populism pits out-of-touch, self-interested "elites" against virtuous "ordinary citizens" (Mede & Schäfer, 2020). In doing so, it frames scientific knowledge as more about scientists than about science and encourages an especially personal brand of "reality monitoring," the processes by which people routinely assess information for its accuracy and the sources of that information for reliability and trustworthiness (Johnson, 2007).

All of these effects conspire to show why people might have been reluctant to use an app promoted by public-health experts who (in the eyes of some citizens) kept changing their minds. After all, if people could avoid a virus that "is not airborne" simply by staying 6 feet (or multiple Australian-animal lengths) away from other people, then why would they need a digital-contact-tracing app?

Threat and control

As COVID-19 spread around the globe and the death toll rose, many people believed an unstoppable threat was marching their way. In the face of a threat, attention narrows, shifting away from day-to-day concerns and toward the source of that threat (Lerner et al., 2015). Although it seems reasonable to assume this heightened focus encouraged some people to embrace digital contact tracing as a way of protecting themselves, that was certainly not the case for all. Why? Because people take protective measures only when they believe they have some control over the threat—when they do not, they often seek to regain a sense of control in maladaptive ways (Witte & Allen, 2000).

For instance, one way people cope with what they think is an uncontrollable threat is to ignore it. People commonly anticipate that good things are more likely to happen to them than bad (even when the probability of either outcome is equal), and they assume that bad things are more likely to happen to others than to themselves (Sharot, 2011). Although this "optimistic bias" provides protection from fear, it could continue to limit public adoption of digital-contact-tracing technologies. Because people are motivated to avoid (and be skeptical of) frightening information that threatens their sense of control, they may not wish to be notified when they are at risk of having contracted a disease (Rehse & Tremöhlen, 2022).

Another way people regain a sense of control is by stoking anger toward agents (even fictitious ones) they hold responsible for threats or simply inept at responding to them. In the pandemic, these agents include government and health officials (Bavel et al., 2020). In addition, when people are angry, they appraise aversive situations as less risky (Lerner et al., 2015). Anger might therefore have pushed people to see the pandemic as less threatening—and digital contact tracing as less necessary—than it was.

Digital-contact-tracing apps themselves also evoked annoyance, even anger, that might have led some users to abandon them. In South Korea, for instance, which did not use the privacy-preserving exposure-notification protocol, the apps displayed the location, age, and sex of people who had tested positive for COVID-19, which in turn allowed users to figure out the identity of some cases. As a result, although users thought their contact-tracing apps were effective, they also expressed concerns about privacy and frustration with delayed updates and frequent alerts (Suh & Li, 2021). People who reported less control over the consequences of using the apps also reported more anger, frustration, and disappointment—factors that predicted decreased intention to continue using them (see also Chuenyindee et al., 2022).

Look and feel

To their owners, phones can be more than just digital devices. Instead, they can be seen as "digital companions" and therefore party to the same types of relationship components seen in human-human interactions: trust, closeness, and so on. In fact, conceptualizing a digital relationship between people and their phones has changed the research landscape (Carolus et al., 2019). Phones, therefore, can be seen as helpful, social, active agents—or disinterested, impersonal, untrustworthy, passive entities (Gronier & Baudet, 2019; Hadi & Valenzuela, 2020). People might see phone apps in similar ways. Indeed, the names of many digital-contact-tracing apps signaled their role as active agents: consider, for example, Fiji's CareFIJI app, Japan's COCOA, Hungary's VirusRadar, or Israel's HaMagen (the "shield" or "protector").

Digital-contact-tracing apps also signaled their role by their "look and feel." For example, Switzerland's app—like many—did not "do" anything obvious unless the user had been exposed. But anecdotally, although the Swiss app aimed to communicate "no news is good news" to users, some people decided "no news means broken." (Of course, sometimes that concern was justified. A bug in the Android version of the exposure-notification framework caused worldwide delays in notifying users, and the Android version of Japan's COCOA app failed to issue notifications for 4 months; Ando, 2021; Kolt, 2021.) By contrast, other apps frequently provided information to users. Germany's app, for example, signaled green when it determined users were low risk and red when there was a clear exposure. In other words, the app frequently communicated its role as both a functioning app and an active protector. It seems plausible that Germans found their app helpful, social, and active, reassuring users they could "offload" cognitive effort onto it (Devine & Otto, 2022; Fellers et al., 2022; Storm & Stone, 2015). These same characteristics might also have encouraged a kind of collaborative reality monitoring—much like the relationship between patients and trusted medical professionals or lawyers and judges (Johnson, 1998).

Finally, remember the ultimate aim of these apps: Regardless of what an app was called or how it communicated, once users reported a positive test, they needed to quarantine. Because quarantine brings with it social isolation and perhaps loss of income, there is probably a fairly low ceiling for how positively disposed people might be toward contact-tracing apps.

Indeed, people in Switzerland joked that the SwissCovid app was like “reverse Tinder”—when the app connected you to someone else, you would end up alone.

Recommendations

Digital contact tracing worked—but it did not work nearly as well as it could have. When these hits and misses are considered in light of psychological science, there are at least five lessons to be learned as humans prepare for the next pandemic.

Lesson 1: close digital divides

Health-care systems must be more digital-aware and better integrated with digital contact tracing. Digital contact tracing itself could also be integrated into other devices people already think of as “health” devices—Garmin and Apple watches, for instance. Of course, these devices are out of reach for many, including the most vulnerable, and public health cannot leave these people behind. Bluetooth wristbands and cards might fill the gap, and because those devices lack GPS, they might also reduce people’s anxiety about threats to their privacy. But these alternatives also need users to take an active role in uploading their stored data (Admiraal et al., 2022; Chambers et al., 2020). Therefore, built into the effectiveness of these alternatives is, at a minimum, a likely failure of prospective memory (for a review, see Rummel & Kvavilashvili, 2023). It stands to reason that any alternative to phone-based contact tracing should not introduce new problems.

Lesson 2: harness the power of semantic context

Rather than wait until the next pandemic, officials should develop templates now for establishing semantic context early in the next crisis. These templates should provide meaningful information—how the new threat spreads and how digital contact tracing can be a powerful weapon to address that threat. As one of psychological science’s classic experiments showed, giving people information up front (“washing clothes”) helps them to make sense of seemingly disconnected bits of information by connecting to existing frameworks. The result is vastly better comprehension and memory (Bransford & Johnson, 1972).

Lesson 3: encourage people to accept uncertainty and update

To the extent public-health officials think conveying scientific uncertainty diminishes their credibility, they run the risk of conveying a state of knowledge more definitive and static than it is (Altenmüller et al., 2021; Retzbach & Maier, 2015). But when scientific knowledge changes, those officials risk pushback from citizens who see the new information not as advances in scientific knowledge but as whimsical personality-driven conflicts. The solution is not to hide uncertainty but to understand how people might draw connections between different types of uncertainty and trust or confidence in science. That is, uncertainty framed as a conflict or controversy among scientists is frequently associated with negative effects, whereas uncertainty that reflects a technical issue, such as the margin of error, is typically associated with positive effects or no effect (for a review, see Gustafson & Rice, 2020). Therefore, as science changes, aspects of the app—such as the way it communicates with users or its threshold for determining risk—might need to change. These changes must be explained to increase or at least maintain trust and confidence, not undermine it.

Lesson 4: messages should help people gain control over threats

Understanding how people see threats is essential for ensuring widespread adoption of digital-contact-tracing technology. When people see threats as uncontrollable, it elicits powerful and aversive emotions that hinder decision-making (Lerner et al., 2015). Scientists need to instill a sense of control about the virus and push the idea that using a contact-tracing app is part of gaining that control. Therefore, messages about digital contact tracing and the apps themselves must give people a sense of control and efficacy. Rather than focusing primarily on numbers of infections, hospitalizations, and deaths, messages should highlight the benefits of digital-contact-tracing apps—stressing their preservation of privacy, ease of use, and proven efficacy in preventing the spread of illness and protecting individuals, their loved ones, and their communities (Bavel et al., 2020).

Lesson 5: improve the user experience

Digital-contract-tracing apps should consistently and overtly signal they are active, helpful, trustworthy agents. Achieving this aim means considering the technology from end to end. Good digital contact tracing is not just the province of epidemiologists and engineers; it needs thoughtful design and marketing to encourage people to accept the technology and use it. Apple, for example, is famous for its ability to encourage excitement about (some might even say “make people believe they need”) entirely new product categories. And although COVID-19 is more important (and less fun) than the iPad, those sorts of lessons still need to be applied. Having said that, there is a tension between encouraging people to use an app and going too far. There are obvious problems, for example, with extreme "gamification" of digital contact tracing—clearly scientists do not want people gathering in crowds chasing "Covidchu," the new mask-wearing Pokémon, or competing to see how many location-based QR codes they can scan in one day.

Instead, contact-tracing apps should clearly signal their active, working status, much like the German app, and send messages to users such as "Your phone is monitoring situations on your behalf. We have no reasons to notify you today." An app could work prospectively to estimate risk, hooking into Google-maps data to determine not simply where the user is but how crowded that place is ("This Starbucks is crowded. You can reduce your risk by wearing a mask and staying near an open window or door"). The key point is that these messages need to be useful in the moment and tailored to the user's lifestyle. But the messages cannot overstep ("Dave, neither of your girlfriends have reported testing positive for COVID-19 this week—and by the way, they know about each other"). Finally, although there is no getting around the reverse-Tinder problem, users could also be given control over many features of their app—its colors, icon, alert signals, and even whether it calls them by name, nickname, or "Springsteen fan." Measures such as these might help to make digital-contact-tracing apps seem more social, helpful, and active, thereby reducing the dissatisfaction associated with a user's reluctance to use them (Suh & Li, 2021).

Once More Unto the Breach: Collective Memory and the Next Pandemic

The hits and misses of digital contact tracing are part of people's "collective memories" of this pandemic—the stories that cultures, countries, and families tell themselves about their collective past (Wertsch & Roediger, 2008). The ability to grapple with the next pandemic hinges on the lessons people learn, remember, and share this time around.

When COVID-19 hit, Western countries had little collective memory of their last pandemic, which began in 1918. Although that pandemic killed more people than both world wars combined, it is rarely commemorated in literature, movies, classrooms, or monuments. It is a lost collective memory, only recently resurfaced to serve as an historical allusion to people's current one (for a review, see Hall & Ross, 2020; Vinitzky-Seroussi & Jalfim Maraschin, 2021).[1]

But the lost collective memory of the 1918 pandemic is not unique in public health. In fact, governments and medical professionals alike were caught off guard in 1918, in part because they, too, had lost collective memory of their last pandemic, in 1889 (Bristow, 2012). By contrast, some countries have grappled successfully with recent pandemics. Take Taiwan, for example. Taiwan established a command center in 1990 to respond to potential pandemics, developed a pandemic plan in 2003 that could quickly respond to new viruses, and already enjoyed widespread adoption of face masks (Summers et al., 2020). In 2017, Taiwan also put in place a comprehensive system of contact tracing for myriad diseases. Although this system was still largely manual, it was exceedingly efficient because it was tightly integrated with a speedy, digital infrastructure (Jian et al., 2020). Taiwan's collective memories of responding to crises, including recent health crises, might have encouraged its citizens to listen to trusted officials and act to defeat the pandemic—both individually and with others.

Perhaps collective memories are associated with the degree to which cultures are "looser" or "tighter" (Gelfand et al., 2011). For instance, lost collective memories might feed into (or be maintained by) looser cultures, such as the United States, New Zealand, and the United Kingdom, where social norms are weak and tolerance of deviant or noncompliant behavior is high. But collective memories might be kept alive by tighter cultures, such as Taiwan, where social norms are strong and tolerance for deviant behavior is low. Note that in 2020, the tightest countries averaged—per million inhabitants—an estimated 21 deaths, while in the loosest countries, this figure was 183 (Gelfand et al., 2021).

The fact that countries such as Taiwan seem to have learned lessons from their collective memories of responding to crises suggests that those memories serve directive functions—teaching lessons and guiding future thinking and behavior, much like people's individual memories are thought to do (Burnell et al., 2022; Pillemer, 2003). The lessons people learn from this pandemic, then, will guide the future of digital contact tracing, for good or bad.

What, then, is the great lesson? One possibility is what George Soper wrote in *Science*:

> The great lesson of the pandemic is to call attention to the prevalence of respiratory diseases in ordinary times, to the indifference with which they are ordinarily regarded and to our present inability to protect ourselves against them. . . . They must be controlled by administrative procedures, and by the exercise of appropriate measures of self-protection.

Soper wrote these words in 1919.

Transparency

Action Editor: Dolores Albarracin
Editor: Interim Editorial Panel
Declaration of Conflicting Interests
The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

ORCID iDs

Maryanne Garry https://orcid.org/0000-0001-6267-8472
Rachel Zajac https://orcid.org/0000-0003-3040-4906
Linda Levine https://orcid.org/0000-0001-9013-3787

Note

1. A similar problem might fuel the drop-off rates in vaccination against even the most pernicious of diseases. When diseases such as polio run rampant, people tend to see vaccines as miracle interventions developed by heroes, and uptake is high. Many people have seen old photos of long lines of people waiting to be vaccinated, for instance, against polio. Often, the vaccines work remarkably well, and the disease becomes rare a generation or two later. But over time, as collective memory fades, the rate of vaccination drops, sometimes below the rate required for herd immunity. Indeed, in September 2022, the New York governor declared a state of emergency over the state's polio outbreak, which was, at that time, suspected to have infected thousands (Fadulu, 2022).

References

Adam, D. (2020). A guide to R—The pandemic's misunderstood metric. *Nature*, *583*(7816), 346–349.

Admiraal, R., Millen, J., Patel, A., & Chambers, T. (2022). A case study of Bluetooth technology as a supplemental tool in contact tracing. *Journal of Healthcare Informatics Research*, *6*(2), 208–227.

Altenmüller, M. S., Nuding, S., & Gollwitzer, M. (2021). No harm in being self-corrective: Self-criticism and reform intentions increase researchers' epistemic trustworthiness and credibility in the eyes of the public. *Public Understanding of Science*, *30*(8), 962–976.

Altmann, S., Milsom, L., Zillessen, H., Blasone, R., Gerdon, F., Bach, R., Kreuter, F., Nosenzo, D., Toussaert, S., & Abeler, J. (2020). Acceptability of app-based contact tracing for COVID-19: Cross-country survey study. *JMIR mHealth and uHealth*, *8*(8), Article e19857. https://doi.org/10.2196/19857

Ando, K. (2021, February 5). *Japan's flawed COVID-19 tracing app is digital black eye for Tokyo*. https://asia.nikkei.com/Spotlight/Comment/Japan-s-flawed-COVID-19-tracing-app-is-digital-black-eye-for-Tokyo

Anglemyer, A., Moore, T. H., Parker, L., Anglemyer, A., Moore, T. H. M., Parker, L., Chambers, T., Grady, A., Chiu, K., Parry, M., Wilczynska, M., Flemyng, E., & Bero, L. (2020). Digital contact tracing technologies in epidemics: A rapid review. *Cochrane Database of Systematic Reviews*, *8*, CD013699. https://doi.org/10.1002/14651858.CD013699

Attridge, N., Pickering, J., Inglis, M., Keogh, E., & Eccleston, C. (2019). People in pain make poorer decisions. *Pain*, *160*(7), 1662–1669.

Ausubel, D. P. (1960). The use of advance organizers in the learning and retention of meaningful verbal material. *Journal of Educational Psychology*, *51*(5), 267–272.

Bavel, J. J. V., Baicker, K., Boggio, P. S., Capraro, V., Cichocka, A., Cikara, M., Crockett, M. J., Crum, A. J., Douglas, K. M., Druckman, J. N., Drury, J., Dube, O., Ellemers, N., Finkel, E. J., Fowler, J. H., Gelfand, M., Han, S., Haslam, S. A., Jetten, J., . . . Willer, R. (2020). Using social and behavioural science to support COVID-19 pandemic response. *Nature Human Behaviour*, *4*(5), 460–471. https://doi.org/10.1038/s41562-020-0884-z

Bente, B. E., van't Klooster, J. W. J. R., Schreijer, M. A., Berkemeier, L., van Gend, J. E., Slijkhuis, P. J. H., Kelders, S. M., & van Gemert-Pijnen, J. E. W. C. (2021). The Dutch COVID-19 contact tracing app (the CoronaMelder): Usability study. *JMIR Formative Research*, *5*(3), Article e27882. https://doi.org/10.2196/27882

Bosco, C., & Cvajner, M. (2021, August). Investigating Italian citizens' attitudes towards Immuni, the Italian contact tracing app. In *IFIP Conference on Human-Computer Interaction* (pp. 34–42). Springer.

Bransford, J. D., & Johnson, M. K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 717–726.

Brewer, D. D., Potterat, J. J., Muth, S. Q., Malone, P. Z., Montoya, P., Green, D. L., Rodgers, H. L., & Cox, P. A. (2005). Randomized trial of supplementary interviewing techniques to enhance recall of sexual partners in contact interviews. *Sexually Transmitted Diseases*, *32*(3), 189–193.

Bristow, N. K. (2012). *American pandemic: The lost worlds of the 1918 influenza epidemic*. Oxford University Press.

Bromme, R., Mede, N. G., Thomm, E., Kremer, B., & Ziegler, R. (2022). An anchor in troubled times: Trust in science before and within the COVID-19 pandemic. *PLOS ONE*, *17*(2), Article e0262823. https://doi.org/10.1371/journal.pone.0262823

Burnell, R., Umanath, S., & Garry, M. (2022). *Collective memories serve similar functions to autobiographical memories* [Manuscript submitted for publication].

Carolus, A., Binder, J. F., Muench, R., Schmidt, C., Schneider, F., & Buglass, S. L. (2019). Smartphones as digital companions: Characterizing the relationship between users and their phones. *New Media & Society*, *21*(4), 914–938.

Cencetti, G., Santin, G., Longa, A., Pigani, E., Barrat, A., Cattuto, C., Lehmann, S., Salathé, M., & Lepri, B. (2021). Digital proximity tracing on empirical contact networks for pandemic control. *Nature Communications*, *12*(1), Article 1655. https://doi.org/10.1038/s41467-021-21809-w

Centers for Disease Control and Prevention. (2022, February 28). *Case investigation and contact tracing: Part of a multipronged approach to fight the COVID-19 pandemic*. https://www.cdc.gov/coronavirus/2019-ncov/php/principles-contact-tracing.html

Chambers, T., Anglemyer, A., Egan, R., Derrett, S., Maclennan, S., Emery, T., Patel, A., & Millen, J. (2020). *Research* *report - Te Whatu trial of the Bluetooth-enabled contact tracing card*. https://www.health.govt.nz/system/files/documents/pages/20201218-te-whatu-research-report.pdf

Chuenyindee, T., Ong, A. K. S., Prasetyo, Y. T., Persada, S. F., Nadlifatin, R., & Sittiwatethanasiri, T. (2022). Factors affecting the perceived usability of the COVID-19 contact-tracing application "Thai chana" during the early COVID-19 omicron period. *International Journal of Environmental Research and Public Health*, *19*(7), Article 4383. https://doi.org/10.3390/ijerph19074383

Danquah, L. O., Hasham, N., MacFarlane, M., Conteh, F. E., Momoh, F., Tedesco, A. A., Jambai, A., Ross, D. A., & Weiss, H. A. (2019). Use of a mobile application for Ebola contact tracing and monitoring in northern Sierra Leone: A proof-of-concept study. *BMC Infectious Diseases*, *19*(1), Article 810. https://doi.org/10.1186/s12879-019-4354-z

Devine, S., & Otto, A. R. (2022). Information about task progress modulates cognitive demand avoidance. *Cognition*, *225*, Article 105107. https://doi.org/10.1016/j.cognition.2022.105107

Eames, K. T., & Keeling, M. J. (2003). Contact tracing and disease control. *Proceedings of the Royal Society B: Biological Sciences*, *270*(1533), 2565–2571.

Einstein, G. O., McDaniel, M. A., & Anderson, F. T. (2018). Multiple processes in prospective memory: Exploring the nature of spontaneous retrieval. In G. Oettingen, A. T. Sevincer, & P. Gollwitzer (Eds.), *The psychology of thinking about the future* (pp. 497–516). The Guilford Press.

Einstein, G. O., McDaniel, M. A., Thomas, R., Mayfield, S., Shank, H., Morrisette, N., & Breneiser, J. (2005). Multiple processes in prospective memory retrieval: Factors determining monitoring versus spontaneous retrieval. *Journal of Experimental Psychology: General*, *134*(3), 327–342.

Epley, N., & Gilovich, T. (2006). The anchoring-and-adjustment heuristic: Why the adjustments are insufficient. *Psychological Science*, *17*(4), 311–318.

Evans, J. R., Dawson, H. R., Chae, H., Goldfarb, D., Fisher, R. P., Dianiska, R. E., Daneshbodi, A., & Meissner, C. A. (2022). Enhancing the effectiveness of contact tracing interviews: A randomized controlled experiment of an enhanced cognitive interview protocol. *American Journal of Infection Control*, *50*(6), 631–637. https://doi.org/10.1016/j.ajic.2021.12.015

Fadulu, L. (2022). *Hochul Declares Polio State of Emergency for New York*. https://www.nytimes.com/2022/09/09/nyregion/new-york-polio-state-of-emergency.html#:~:text=Gov.,further%20hold%20in%20the%20state

Fellers, C., Miyatsu, T., & Storm, B. C. (2022). Remembering what to do when the time comes: The effects of offloading in a complex prospective memory task. *Journal of Experimental Psychology: Applied*. Advance online publication. https://doi.org/10.1037/xap0000449

Funk, C., Hefferon, M., Kennedy, B., & Johnson, C. (2019). *Trust and mistrust in Americans' views of scientific experts*. Pew Research Center.

Gabbert, F., Hope, L., Carter, E., Boon, R., & Fisher, R. (2015). The role of initial witness accounts within the investigative process. In G. Oxburgh, T. Myklebust, T. Grant, & R. Milne (Eds.), *Communication in investigative and legal contexts: Integrated approaches from forensic psychology, linguistics and law enforcement* (pp. 107–131). Wiley-Blackwell.

Gardner, B. J., & Kilpatrick, A. M. (2021). Contact tracing efficiency, transmission heterogeneity, and accelerating COVID-19 epidemics. *PLOS Computational Biology*, *17*(6), Article e1009122. https://doi.org/10.1371/journal.pcbi.1009122

Garry, M., Hope, L., Zajac, R., Verrall, A. J., & Robertson, J. M. (2021). Contact tracing: A memory task with consequences for public health. *Perspectives on Psychological Science*, *16*(1), 175–187.

Gelfand, M. J., Jackson, J. C., Pan, X., Nau, D., Pieper, D., Denison, E., Dagher, M., Van Lange, P. A. M., Chiu, C. Y., & Wang, M. (2021). The relationship between cultural tightness–looseness and COVID-19 cases and deaths: A global analysis. *The Lancet Planetary Health*, *5*(3), e135–e144. https://doi.org/10.1016/S2542-5196(20)30301-6

Gelfand, M. J., Raver, J. L., Nishii, L., Leslie, L. M., Lun, J., Lim, B. C., Duan, L., Almaliach, A., Ang, S., Arnadottir, J., Aycan, Z., Boehnke, K., Boski, P., Cabecinhas, R., Chan, D., Chhokar, J., D'Amato, A., Ferrer, M., Fischlmayr, I. C., . . . Yamaguchi, S. (2011). Differences between tight and loose cultures: A 33-nation study. *Science*, *332*(6033), 1100–1104. https://doi.org/10.1126/science.1197754

Gohar, A., Adams, A., Gertner, E., Sackett-Lundeen, L., Heitz, R., Engle, R., Haus, E., & Bijwadia, J. (2009). Working memory capacity is decreased in sleep-deprived internal medicine residents. *Journal of Clinical Sleep Medicine*, *5*(3), 191–197.

Google. (2016). *How people discover, use, and stay engaged with apps*. https://think.storage.googleapis.com/docs/how-users-discover-use-apps-google-research.pdf

Greenhalgh, T., Ozbilgin, M., & Tomlinson, D. (2022). How covid-19 spreads: Narratives, counter narratives, and social dramas. *The BMJ*, *378*, Article e069940. https://doi.org/10.1136/bmj-2022-069940

Grondin, S. (2010). Timing and time perception: A review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception, & Psychophysics*, *72*(3), 561–582.

Gronier, G., & Baudet, A. (2019). Does progress bars' behavior influence the user experience in human-computer interaction? *Psychology and Cognitive Sciences – Open Journal*, *5*, 6–13.

Gustafson, A., & Rice, R. E. (2020). A review of the effects of uncertainty in public science communication. *Public Understanding of Science*, *29*(6), 614–633.

Hadi, R., & Valenzuela, A. (2020). Good vibrations: Consumer responses to technology-mediated haptic feedback. *Journal of Consumer Research*, *47*(2), 256–271.

Hall, T. F., & Ross, D. A. (2020). Can the UK win back its collective memory of epidemics? *BMJ Military Health*, *167*(2), Article 73. https://doi.org/10.1136/bmjmilitary-2020-001634

Hope, L., & Gabbert, F. (2019). Expanding the legacy of the cognitive interview: Developments and innovations in evidence-based investigative interviewing. In J. J.

Dickinson, N. Schreiber Compo, R. Carol, B. L. Schwartz, & M. McCauley (Eds.), *Evidence-based investigative interviewing: Applying cognitive principles* (pp. 42–55). Routledge.

Hope, L., Mullis, R., & Gabbert, F. (2013). Who? What? When? Using a timeline technique to facilitate recall of a complex event. *Journal of Applied Research in Memory and Cognition*, *2*, 20–24.

Jian, S. W., Cheng, H. Y., Huang, X. T., & Liu, D. P. (2020). Contact tracing with digital assistance in Taiwan's COVID-19 outbreak response. *International Journal of Infectious Diseases*, *101*, 348–352.

Johnson, M. K. (1998). Individual and cultural reality monitoring. *The Annals of the American Academy of Political and Social Science*, *560*(1), 179–193.

Johnson, M. K. (2007). Reality monitoring and the media. *Applied Cognitive Psychology*, *21*(8), 981–993.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*, *114*(1), 3–28.

Joung, S. Y., Ebinger, J. E., Sun, N., Liu, Y., Wu, M., Tang, A. B., Prostko, J. C., Frias, E. C., Stewart, J. L., Sobhani, K., & Cheng, S. (2022). Awareness of SARS-CoV-2 Omicron variant infection among adults with recent COVID-19 seropositivity. *JAMA Network Open*, *5*(8), Article e2227241. https://doi.org/10.1001/jamanetworkopen.2022.27241

Kolt, K. (2021, January 13). *Google has rolled out a fix for a COVID-19 tracking app loading issue*. https://www.engadget.com/android-covid-19-tracking-apps-issues-google-exposure-notification-151816204.html

Lerner, J. S., Li, Y., Valdesolo, P., & Kassam, K. S. (2015). Emotion and decision making. *Annual Review of Psychology*, *66*, 799–823.

Lindsay, D. S. (2014). Memory source monitoring applied. In T. J. Perfect & D. S. Lindsay (Eds.), *The Sage handbook of applied memory* (pp. 59–75). Sage.

Machida, M., Kikuchi, H., Kojima, T., Nakamura, I., Saito, R., Nakaya, T., Hanibuchi, T., Takamiya, T., Odagiri, Y., Fukushima, N., Amagasa, S., Watanabe, H., & Inoue, S. (2022). Unwillingness to cooperate with COVID-19 contact tracing in Japan. *Public Health*, *210*, 34–40. https://doi.org/10.1016/j.puhe.2022.06.018

Mantonakis, A., Rodero, P., Lesschaeve, I., & Hastie, R. (2009). Order in choice: Effects of serial position on preferences. *Psychological Science*, *20*(11), 1309–1312.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology*, *82*(4), 715–726.

Mede, N. G., & Schäfer, M. S. (2020). Science-related populism: Conceptualizing populist demands toward science. *Public Understanding of Science*, *29*(5), 473–491.

Munzert, S., Selb, P., Gohdes, A., Stoetzer, L. F., & Lowe, W. (2021). Tracking and promoting the usage of a COVID-19 contact tracing app. *Nature Human Behaviour*, *5*(2), 247–255.

Navarre, A., Didierjean, A., & Thomas, C. (2022). Anchoring effect induces false memories. *Psychonomic Bulletin & Review*, *29*(6), 2240–2246. https://doi.org/10.3758/s13423-022-02147-4

Oberfeld, D., Hots, J., & Verhey, J. L. (2018). Temporal weights in the perception of sound intensity: Effects of sound duration and number of temporal segments. *The Journal of the Acoustical Society of America*, *143*(2), 943–953.

Patel, J. A., Nielsen, F., Badiani, A. A., Assi, S., Unadkat, V. A., Patel, B., Ravindrane, R., & Wardle, H. (2020). Poverty, inequality and COVID-19: The forgotten vulnerable. *Public Health*, *183*, 110–111.

Pichert, J. W., & Anderson, R. C. (1977). Taking different perspectives on a story. *Journal of Educational Psychology*, *69*(4), 309–315.

Pillemer, D. (2003). Directive functions of autobiographical memory: The guiding power of the specific episode. *Memory*, *11*(2), 193–202.

Porta, M. (2014). *A dictionary of epidemiology* (7th ed.). Oxford University Press.

Prakash, A. V., & Das, S. (2022). Explaining citizens' resistance to use digital contact tracing apps: A mixed-methods study. *International Journal of Information Management*, *63*, Article 102468. https://doi.org/10.1016/j.ijinfomgt.2021.102468

Ramsetty, A., & Adams, C. (2020). Impact of the digital divide in the age of COVID-19. *Journal of the American Medical Informatics Association*, *27*(7), 1147–1148.

Rehse, D., & Tremöhlen, F. (2022). Fostering participation in digital contact tracing. *Information Economics and Policy*, *58*, Article 100938. https://doi.org/10.1016/j.infoecopol.2021.100938

Retzbach, A., & Maier, M. (2015). Communicating scientific uncertainty: Media effects on public engagement with science. *Communication Research*, *42*(3), 429–456.

Rizzo, E. (2020). COVID-19 contact tracing apps: The 'elderly paradox.' *Public Health*, *185*, Article 127. https://doi.org/10.1016/j.puhe.2020.06.045

Rummel, J., & Kvavilashvili, L. (2023). Current theories of prospective memory and new directions for theory development. *Nature Reviews Psychology*, *2*, 40–54. https://doi.org/10.1038/s44159-022-00121-4

Salathé, M., Althaus, C. L., Anderegg, N., Antonioli, D., Ballouz, T., Bugnion, E., Čapkun, S., Jackson, D., Kim, S. I., Larus, J., Low, N., Lueks, W., Menges, D., Moullet, C., Payer, M., Riou, J., Stadler, T., Troncoso, C., Vayena, E., & von Wyl, V. (2020). Early evidence of effectiveness of digital contact tracing for SARS-CoV-2 in Switzerland. *Swiss Medical Weekly*, *150*, Article w20457. https://doi.org/10.4414/smw.2020.20457

Saurabh, S., & Prateek, S. (2017). Role of contact tracing in containing the 2014 Ebola outbreak: A review. *African Health Sciences*, *17*(1), 225–236.

Schacter, D. L. (2022). Memory sins in applied settings: What kind of progress? *Journal of Applied Research in Memory and Cognition*, *11*(4), 445–460.

Schaller, M. (2008). Evolutionary bases of first impressions. In N. Ambady & J. J. Skowronski (Eds.), *First impressions* (pp. 15–34). The Guilford Press.

Shahid, Z., Kalayanamitra, R., McClafferty, B., Kepko, D., Ramgobin, D., Patel, R., & Jain, R. (2020). COVID-19 and older adults: What we know. *Journal of the American Geriatrics Society*, *68*(5), 926–929.

Sharot, T. (2011). The optimism bias. *Current Biology*, *21*(23), R941–R945.

Smith, A. P. (2012). Effects of the common cold on mood, psychomotor performance, the encoding of new information, speed of working memory and semantic processing. *Brain, Behavior, and Immunity*, *26*(7), 1072–1076.

Smith, A. P. (2013). Twenty-five years of research on the behavioural malaise associated with influenza and the common cold. *Psychoneuroendocrinology*, *38*(6), 744–751.

Soper, G. A. (1919). The lessons of the pandemic. *Science*, *49*(1274), 501–506.

Storm, B. C., & Stone, S. M. (2015). Saving-enhanced memory: The benefits of saving on the learning and remembering of new information. *Psychological Science*, *26*(2), 182–188.

Suh, A., & Li, M. (2021). Digital tracing during the COVID-19 pandemic: User appraisal, emotion, and continuance intention. *Sustainability*, *13*(2), Article 608. https://doi.org/10.3390/su13020608

Summers, J., Cheng, H. Y., Lin, H. H., Barnard, L. T., Kvalsvig, A., Wilson, N., & Baker, M. G. (2020). Potential lessons from the Taiwan and New Zealand health responses to the COVID-19 pandemic. *The Lancet Regional Health-Western Pacific*, *4*, Article 100044. https://doi.org/10.1016/j.lanwpc.2020.100044

Swanson, K. C., Altare, C., Wesseh, C. S., Nyenswah, T., Ahmed, T., Eyal, N., Hamblion, E. L., Lessler, J., Peters, D. H., & Altmann, M. (2018). Contact tracing performance during the Ebola epidemic in Liberia, 2014-2015. *PLOS Neglected Tropical Diseases*, *12*(9), Article e0006762. https://doi.org/10.1371/journal.pntd.0006762

Thole, S., Kalhoefer, D., An der Heiden, M., Nordmann, D., Daniels-Haardt, I., & Jurke, A. (2019). Contact tracing following measles exposure on three international flights, Germany, 2017. *Eurosurveillance*, *24*(19), Article 1800500. https://doi.org/10.2807/1560-7917.ES.2019.24.19.1800500

Tomczyk, S., Barth, S., Schmidt, S., & Muehlan, H. (2021). Utilizing health behavior change and technology acceptance models to predict the adoption of COVID-19 contact tracing apps: Cross-sectional survey study. *Journal of Medical Internet Research*, *23*(5), Article e25447. https://doi.org/10.2196/25447

Troncoso, C., Payer, M., Hubaux, J. P., Salathé, M., Larus, J., Bugnion, E., & Pereira, J. (2020). *Decentralized privacy-preserving proximity tracing*. arXiv. https://doi.org/10.48550/arXiv.2005.12273

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases: Biases in judgments reveal some heuristics of thinking under uncertainty. *Science*, *185*(4157), 1124–1131.

Vinitzky-Seroussi, V., & Jalfim Maraschin, M. (2021). Between remembrance and knowledge: The Spanish Flu, COVID-19, and the two poles of collective memory. *Memory Studies*, *14*(6), 1475–1488.

Wilson, A. M., Aviles, N., Petrie, J. I., Beamer, P. I., Szabo, Z., Xie, M., McIllece, J., Chen, Y., Son, Y. J, Halai, S., White, T., Ernst, K. C., & Masel, J. (2022). Quantifying SARS-CoV-2 infection risk within the Google/Apple Exposure Notification framework to inform quarantine recommendations. *Risk Analysis*, *42*(1), 162–176.

Watts, G. (2020). COVID-19 and the digital divide in the UK. *The Lancet Digital Health*, *2*(8), e395–e396.

Wertsch, J. V., & Roediger, H. L. (2008). Collective memory: Conceptual foundations and theoretical approaches. *Memory*, *16*(3), 318–326.

Witte, K., & Allen, M. (2000). A meta-analysis of fear appeals: Implications for effective public health campaigns. *Health Education & Behavior*, *27*, 591–615.

Wu, Y., Kang, L., Guo, Z., Liu, J., Liu, M., & Liang, W. (2022). Incubation period of COVID-19 caused by unique SARS-CoV-2 strains: A systematic review and meta-analysis. *JAMA Network Open*, *5*(8), Article e2228008. https://doi.org/10.1001/jamanetworkopen.2022.28008

Wymant, C., Ferretti, L., Tsallis, D., Charalambides, M., Abeler-Dörner, L., Bonsall, D., Hinch, R., Kendall, M., Milsom, L., Ayres, M., Holmes, C., Briers, M., & Fraser, C. (2021). The epidemiological impact of the NHS COVID-19 app. *Nature*, *594*(7863), 408–412. https://doi.org/10.1038/s41586-021-03606-z

Yasaka, T. M., Lehrich, B. M., & Sahyouni, R. (2020). Peer-to-peer contact tracing: Development of a privacy-preserving smartphone app. *JMIR mHealth and uHealth*, *8*(4), Article e18936. https://doi.org/10.2196/18936

Zebrowitz, L. A. (2017). First impressions from faces. *Current Directions in Psychological Science*, *26*(3), 237–242.

Zebrowitz, L. A., & Collins, M. A. (1997). Accurate person perception at zero acquaintance: The affordances of a Gibsonian approach. *Personality and Social Psychology Review*, *1*, 204–223.

Zhang, R., Li, Y., Zhang, A. L., Wang, Y., & Molina, M. J. (2020). Identifying airborne transmission as the dominant route for the spread of COVID-19. *Proceedings of the National Academy of Sciences, USA*, *117*(26), 14857–14863.

Zhang, Y., Yang, H., Li, S., Li, W. D., Wang, J., & Wang, Y. (2021). Association analysis framework of genetic and exposure risks for COVID-19 in middle-aged and elderly adults. *Mechanisms of Ageing and Development*, *194*, Article 111433. https://doi.org/10.1016/j.mad.2021.111433