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CONTACT TRACING: A MEMORY TASK with CONSEQUENCES for PUBLIC HEALTH

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Abstract

In the battle for control of COVID-19, we have few weapons. Yet contact tracing is among the most powerful. Contact tracing is the process by which public health officials identify people, or contacts, who have been exposed to a person infected with a pathogen or another hazard. For all its power, though, contact tracing yields a variable level of success. One reason is that contact tracing's ability to break the chain of transmission is only as effective as the proportion of contacts who are actually traced. In part, this proportion turns on the quality of the information that infected people provide, which makes human memory a crucial part of the efficacy of contact tracing. Yet the fallibilities of memory, and the challenges associated with gathering reliable information from memory, have been grossly underestimated by those charged with gathering it. We review the witness and investigative interviewing literatures, identifying interrelated challenges that parallel those in contact tracing, as well as approaches for addressing those challenges.

On the face of it, the 61-year-old woman had an uneventful couple of weeks. She went to church, had a minor fender-bender, and enjoyed a buffet lunch with a friend. But over that period in February 2020, she also became the hub of South Korea's COVID-19 outbreak—an outbreak that, at the time, rapidly became the largest outside of China (Korea Centers for Disease Control & Prevention, 2020). The woman, known as Patient 31, achieved this unenviable status for two reasons. First, her church defied the city of Deagu's restrictions on large gatherings. And second, simply by going about their normal day-to-day activities, the average person infected with COVID-19 will spread it to between 2 and 3 people, resulting in the exponential growth rates we are now all too familiar with. Over just 10 days, Patient 31 came into contact with 1600 people. At a single church service, she is thought to have transmitted the virus to 37 people, and significant clusters of infection subsequently emerged at two of the other locations she visited. We know Patient 31's movements, whom she infected and when—and more to the point, how South Korea controlled the infected cluster of people—because of a public-health procedure called *contact tracing*.

What is Contact Tracing?

Contact tracing is the process by which public health officials identify people, or *contacts*, who have been exposed to a person, or *index case*, infected with a pathogen or another hazard—such as an environmental contagion, or contaminated food (Porta, 2014). Contacts identified through tracing are then targeted for therapeutic or preventative treatment, which may include isolation, quarantine or other behavioral interventions. Contact tracing is routinely used to identify and treat people exposed to others with HIV or tuberculosis, to vaccinate those exposed to Ebola, or isolate those exposed to measles (Porta, 2014; Saurabh & Prateek, 2017; Swanson et al., 2018; Thole et al., 2019). Contact tracing programs define "exposure" according to each pathogen's mode of transmission. For airborne diseases, such as tuberculosis, varicella ("chicken pox"), and measles, exposure is defined as having been in the same indoor space as an infected person. For sexually-transmitted infections, exposure is defined as sexual contact. In all cases, the definition includes a minimum duration, frequency, or intensity of exposure which accounts for the probability that transmission has, in fact, occurred. When contact tracing is conducted rapidly and efficiently, it can break the chain of transmission from contacts to other people, effectively putting the brakes on the spread of an infectious pathogen (Eames & Keeling, 2003).

When it comes to COVID-19, the purpose of contact tracing is to identify people who have been infected—or possibly infected—and isolate them from others. Because COVID-19 is usually transmitted by infectious droplets in coughs and sneezes, exposure is defined as having been within 2 meters of a probable or confirmed case for at least 15 minutes. Accordingly, contacts are people who meet these criteria. Contacts are identified, or *traced*, by asking index cases to recall their contacts during an interval associated with a high probability of infection, which is two days prior to when they when they started having symptoms and until they are isolated (CDC, July 2020).

Different countries have adopted various combinations of contact tracing, isolation, social distancing and "lockdowns" to achieve control of COVID-19 outbreaks. For example, contact tracing and isolation, in tandem with widespread testing, was employed in the absence of lockdowns in Chinese provinces outside of Hubei and in South Korea (Hellewell et al., 2020; Ministry of Health, 2020). New Zealand, Taiwan, and Germany have used these strategies, as well as social distancing, to control relatively low numbers of cases. All now have good chances of controlling the virus. In Singapore, contact tracing helped officials detect half of their early cases and controlled the virus for two months with this approach alone, before a surge of infections in crowded migrant dormitories then required a lockdown (Beaumont, 2020). By contrast, the United States and United Kingdom have deployed resources inconsistently and implemented policies weakly in many regions at the outset of the COVID-19 outbreak, and endured high rates of infection.

In the battle for control of COVID-19, we have few weapons, and contact tracing is among the most powerful. Indeed, epidemiological models that simulate rates of transmission, infection, onset of symptoms in combination with speed and efficacy of contact tracing suggest that—when conducted quickly and comprehensively—contact tracing could control the majority of outbreaks (see, for example, Hellewell et al., 2020). Yet these same models show that even small changes to basic assumptions really matter: change the base rate of infection in the community; the number of people an infected person infects; how long it takes for an infected person to self-isolate, or the proportion of identified contacts actually located, and the theoretical effectiveness of contact tracing varies wildly (Holmdahl & Buckee, 2020). In practice, contact tracing will likely need to be adopted in conjunction with improved respiratory hygiene measures, social distancing, and possibly masks to achieve reliable control.

To cognitive scientists, news of contact tracing's variable level of success comes as no surprise. After all, contact tracing's ability to prevent onwards transmission is only as effective as the quality of the information that index cases provide. Hidden in the variable a contact tracing model might call "completeness" lurks another problem: human memory.

An Overview of Memory

To understand how memory creates a problem for contact tracing first requires an understanding of how memory works (for a basic introduction to these aspects of memory, see, for example, McDermott & Roediger, 2018). The problems begin right at encoding, when you have any experience you don't know you'll need to remember a few days later. When you are in the coffee shop waiting with your buddies for your half-caff nitro oat milk grande to-go, you are not taking in all the information in your environment. Instead, you're making a selective first-cut that depends on your attention, arousal, emotion, lighting, meaning, plans, goals, expectations, and the capacity of your cognitive system. What's more, you are recoding information to make it more meaningful, creating associations and drawing inferences as you go. Encoding, therefore, can help produce a memory that is both less than what happened and more than what happened.

Even if you were to encode a complete memory, it would not sit around inert, waiting for a public health official to get in touch. Memories are updated with information from many, varied sources—while at the same time losing information about what those sources were (Johnson et al., 1993; Lindsay & Perfect, 2014). Other coffees, on other days, in other locations are just some of the myriad sources of potential interference. And worse, each time you bring that memory to mind, you have yet another opportunity to infuse it with thoughts, images, feelings, inferences, imagined counterfactuals, and just about any kind of information you might have encountered after that event—or, sometimes, about an event that never happened at all (for a review, see Schacter & Loftus, 2013; see also Garry et al., 2005).

But days later, when you have symptoms of COVID-19, a public health official will interview you about your contacts. Will you remember the coffee shop? If so, will you remember when you were there, who else was there, whether you spoke with anyone, and how long you stayed? This is the process of retrieval. During retrieval, the aim is for the contact tracer conducting the interview to cue a stored network of relevant information so it becomes become more activated than usual. If enough features of a memory are activated—typically, when cue and the features of that memory are both strong and distinctive—that memory is retrieved (Anderson, 1983; Nairne, 2002).

When it comes to retrieval, though, just because memories could be retrieved does not mean they will be; this distinction is the difference between *availability* and *accessibility* described by Tulving and Pearlstone (1966). And so you might find yourself unable to access some of what you previously encoded; this loss of access can be fleeting or persistent. Does it help that the contact tracer impresses the urgency of the situation on you? No. Merely learning that a seemingly-ordinary experience is now—days later—significant rarely helps people remember more about it (Charman et al., 2019).

As much as these apparent shortcomings of memory might frustrate you, or the public health official, or inject error into the process of contact tracing, it might help to know that these “shortcomings" are probably adaptive. That is, forgetting encourages stimulus generalisation, and the ability to update our memories with new knowledge is crucial for our survival (Riccio et al., 1994). But in the moment, these memory processes conspire to produce someone who could have important, accurate information for public health officials, but who is temporarily or permanently unable to produce it. And gathering this information is the overarching challenge for contact tracing.

Historically, the challenges associated with gathering reliable information from memory have been vastly underestimated by those charged with gathering it. Nowhere is this challenge more clearly or sharply delineated than in situations in which professionals attempt to elicit information from witnesses—whether those witnesses are, to varying degrees, victims, bystanders, or suspects. In addition, interviews that have taken little or no account of how memory actually works (or goes wrong) have been associated with failures to secure reliable investigative or intelligence information. The hunt for the mythical John Doe 2 in the Oklahoma domestic terrorist attack; the pursuit of the murderer of the Swedish Minister for Foreign Affairs; the impact of the Iraqi information “Curveball,” and the cases of numerous DNA exonerees, documented by the Innocence Project, all illustrate profound failures of “information gathering,” in which bad interviewing practices were largely responsible for generating unreliable or outright false leads. The result? A diversion of valuable time and other resources, and a host of associated negative outcomes. Cases such as these have led to decades of research into what goes wrong in witness interviews and how to get it right. At the most basic level, this research gives us a starting point for improving contact tracing, because when we are talking about contact tracing, we are really talking about witness memory. When Patient

31 had lunch with her friend, she became a witness to an event in which the virus was potentially transmitted, and a suspect who might have transmitted it to others.

Gathering information from witnesses presents five interrelated challenges. First, even the most cooperative *witnesses unwittingly omit information*. That is, contrary to common misconception, just because witnesses want to be helpful, they often do not spontaneously retrieve or report complete memories—even for salient or otherwise memorable events. Second, even when they do report memories, *witnesses are often imprecise;* they don't provide enough useful ("actionable") detail. Third, the way that people remember and the information they use to do so can mean that *witnesses make mistakes*—these mistakes can range from minor distortions to false memories for entire events that never occurred. Fourth, all witnesses are not created equal. Although pulling information from memory can pose problems for anyone, some *witnesses have vulnerabilities* that can make remembering particularly difficult. Finally, even when none of these challenges exist, there are myriad reasons why *witnesses can be reluctant to report what they recall.*

The Parallel Challenges for Contact Tracing

The efficacy of contact tracing hinges on the public health system's ability to gather the right information quickly. To scientists of memory, contact tracing needs to gather complete, precise, and accurate information from witnesses to an ill-defined event. If we conceptualize people who are infected as important witnesses to the spread of a virus, we see that contact tracers face the same five challenges as their witness-interviewing counterparts.

Witnesses Unwittingly Omit Information

The frustrating reality of contact tracing is that retrospective importance and urgency are unlikely to translate into better recall. That is, to the extent that arousal, stress, and emotion engage processes that prioritize attention and enhance memory, many of the locations we move through, the activities we engage in, and the encounters we have, are entirely mundane (Mather & Sutherland, 2011). We go to the gym, buy groceries, get a haircut, pick up a pizza, re-fuel the car. These ordinary encounters vary in their risk of viral transmission. Some locations are densely crowded, but outside (say, a trip to the farmer's market on a Saturday morning); others are less crowded but people stay a long time (writing that novel in a coffee shop). Still other locations vary in how much they encourage interaction (workplaces, religious gatherings, or yoga). Nonetheless, many of these situations—and even the riskiest among them—are simply the backdrop of our daily lives. Nothing much about them stands out in memory (Johnson et al., 1993).

Omitting information presents the greatest challenge for contact tracing. The failure to recall a single event with a contact—an incidental conversation with a friend or neighbor, for example—can mean an unidentified person unknowingly transmits the virus in the community. Worse still, failure to recall an episode involving multiple close contacts, such as forgetting a night at the movies, multiplies those consequences. But omitting contacts is not the only way to lose important information about who might be infected. Contacts can also be lost when index cases fail to recall symptoms in their memory reports, or the date at which symptoms began. An index case might remember, for example, that her fever began Thursday, but neglect to report—or even to remember—that she had a sore throat for three days prior. Here, one small omission leads to three days of missed contacts.

Witnesses are Imprecise

Even when people recall relevant behavior, there is no guarantee they will spontaneously report that behavior with enough detail for it to be useful. For example, an index case might recall visiting the supermarket, but fail to report his encounters while there, such as an extended conversation with a store employee. Or he might recall an encounter but not report who it was with, how long it was with, or the distance between them. Or his memory for specific detail may be lacking—"Some employee near the kale" might make contact tracing extremely difficult. Even if the index case does recall an encounter and who it was with, the definition of a close contact requires him to use two elements of precision that we know witnesses struggle to report: distance and time (Grondin, 2010). Was the conversation more than 15 minutes? Was the employee by the kale less than 2 meters away?

Witnesses Make Mistakes

Memory reports are not only notoriously incomplete, they are also notoriously error-prone (see, for example, Schacter, 1999). Even if the information that made it into memory was 100% accurate and stayed that way over time, people still make errors when they try to retrieve that information after some delay. Some of these errors occur when people over-rely on what *usually* happens ("On Fridays I usually go to the hairdressers"). Here, witnesses who guess or speculate in an attempt to help—or are encouraged to do so by a well-meaning interviewer—might unwittingly provide erroneous information that produces false leads and wastes resources. Worse, as information that helps them remember the source of that information fades, guessing or speculating might also cement an inaccurate version of events in their own memory, making follow-up interviewing useless at best (Johnson et al., 1993).

People also make retrieval errors because it is hard to identify the source of information that comes to mind—in other words, it is hard to distinguish what they experienced during the target event from information that encountered somewhere else. At the broadest level, these source monitoring problems might lead a witness to erroneously recall meeting a friend for coffee, for instance, when in fact she only planned to do it—simply because she meets her friend for coffee at the same time and place each week. Errors like these can also occur when someone combines details of several genuine events. Rachel might remember visiting the cinema with Fiona on Friday, when actually it was on Monday (right location, right person, wrong time), or bumping into Dave in High Street on Wednesday, when actually it was Mark (right location, right time, wrong person). These faulty recollections can be particularly easy to mistake for real experiences, because their components all really happened—just not together as a single event. What compounds the problem is that people prefer to engage in easy strategies rather than the more difficult, yet more reliable, ones that encourage better source monitoring (Nash et al., 2017). Worse still, even in high-stakes medical situations, people have difficulty assessing the accuracy of their own memories for life-or-death actions (Sharman et al., 2008).

Witnesses Have Vulnerabilities

We know that even when operating at an optimal level of cognitive capacity, people's memory for incidental information is likely to be poor (Misra et al., 2018). But we also know that many witnesses are not operating at that level—whether due to young or old age, low levels of intellectual functioning, mental distress, or other factors. These sorts of vulnerabilities often require special efforts to assist recall and reporting (Mueller-Johnson & Ceci, 2007; Zajac & Brown, 2018).

With contact tracing, there is an important additional consideration: the index cases are generally unwell, and sometimes in pain. Pain disrupts performance on a variety of cognitive tasks, and acute illness—including viral infection—is associated with impaired executive function and working memory (Attridge et al., 2019; Smith, 2012; see Smith, 2013, for a review). Index cases are probably concerned about their own health, and the impact of isolation on their family, friends, and work. Impairments and distractions such as these might well hinder cases' abilities to recall details, or even engage in retrieval activities necessary to remember those details. Indeed, it is worth noting that in the only empirical test of contact-tracing interviewing, which used a distracting task to simulate the effects of illness-related cognitive impairment, ordinary healthy people struggled to report details—even when interviewers made special efforts to assist retrieval (Mosser & Evans, 2019). Yet emerging research shows even "mild" cases of COVID-19 infection can be accompanied by delirium, psychosis, and cognitive impairment of variable duration (Paterson et al., 2020).

Witnesses can be Reluctant to Report what they Recall

Successful interviews depend on people's willingness to cooperate and their motivation to report information (Alison et al., 2013). Yet there are a variety of reasons that index cases might not be fully cooperative (Hope, 2019). They might not be motivated to put effort into an interview. They may have limited understanding about the utility of the information they provide, or lack of faith in the contact tracer or agency that person represents. They might not want to share private information about themselves—perhaps because they are skeptical (or even scared) about how, when, and by whom that information will be used. They may be worried about scammers or infringements on their private data. They might be embarrassed or ashamed to reveal that they broke some "rules" during lockdown, or they may fear the punitive consequences of doing so. They might want to conceal other aspects of their behavior. Those cheating on a spouse, engaging in criminal activity, or living with an undocumented migrant might, for example, omit information or account for their time in a deliberately inaccurate way (Confrey, 2017; Papp et al., 2017; Spencer & Stern, 2001; Westera & Powell, 2015). Most pragmatically, some people might deliberately conceal their activities and symptoms from friends, family, or even public health officials in order to continue working, or lose social support. In the case of COVID-19, these concerns are not simply hypothetical; in recent work, half the people who said they had symptoms also said they concealed at least some of those symptoms (O'Connor & Evans, 2020).

What Can Help?

If we conceptualize infected people as important witnesses to the spread of a virus, we then can align this new challenge with existing scientific literature. Despite the fact that contact tracing is the main COVID-19 infection control strategy available, standardized interview protocols that are informed by research on memory are strangely absent. Health agencies such as the World Health Organization or Center for Disease Control and Prevention have produced general guidelines for contact tracing (WHO, 2015) with a focus on generating lists of contacts—but this guidance typically contains minimal information about how to actually conduct contact tracing interviews, and what kinds of questions to ask (see Mosser & Evans, 2019). Compounding the problem is the lack of grounding in basic principles of memory, and very limited research on contact tracing interviews—especially in the epidemiology literature (e.g. Brewer et al., 1999). For instance, the word "memory" does not appear in the WHO guidelines, and contact tracers are advised to actively listen, adjust the interview where necessary, and ask probing questions. Johns Hopkins is currently offering a course on Coursera called "COVID-19 Contact Tracing," in which students learn nothing about the relevant principles of memory—and instead are instructed to listen actively, be quiet so the interviewee can talk and think, and avoid questions such as "Now, I'd like to understand about what you did and who you saw over the past week. You didn't see anyone, right?" In short, when it comes to COVID-19, we know the *what*—index cases need to use the duration of their symptoms to identify their contacts during that time and two days prior (Yasaka et al., 2020). But the *how* is much less clear.

The good news is that we already have a considerable body of empirical and applied literature telling us how to better elicit accurate and detailed information from people's memories. In the field of investigative interviewing, interviewing protocols have been developed to address the challenges typically associated with accessing people's memories. These protocols typically provide a structured yet flexible combination of psychologically-informed techniques and, broadly speaking, significantly increase the amount of information elicited with little meaningful cost to accuracy.

We also know that four core features of an interview contribute to a better memory report. First, a good interview starts before the interview asks a question; the *development of good rapport* between the interviewer and the witness is crucial. Second, *managing the witness's expectations* about his or her role in the interview can help overcome reluctance to report information and increase precision when doing so. Third, the questioning strategy matters; interviewers need to use *questions and instructions that promote both detail and accuracy*. Finally, interviewers can further encourage a better memory report by adopting *retrieval support techniques* and—if possible—freeing the witness to report the information they remember in a way that is compatible with how they remember it (Hope & Gabbert, 2019; Fisher, 2010; Fisher et al., 2014). Let us take a closer look at each of the features in turn.

Development of Good Rapport

In a formal situation designed to gather information, rapport-building can broadly be described as personalizing the interview: presenting an approachable demeanor, expressing genuine interest in the interviewee, and paying active attention during the interview (Gabbert et al., under review; see also Mooney, 2020). Actions that help build rapport can all be implemented regardless of whether interviews are conducted in person face-to-face, with social distancing and PPE in place, or even remotely, during an online interview.

On the surface, these elements might seem obvious, yet they are easily overlooked when contact tracers are conducting similar interviews over and over again, over many days and many cases. Contact tracers might see rapport-building as a perfunctory part of the interview that is "done at the beginning" as opposed to an ongoing process, or—worse still—they might be following a script that doesn't allow for building rapport at all. When rapport-building is done well, however, and maintained throughout the interview, it helps reporting in meaningful ways. Indeed, in the psychology and law literature, the level of rapport between the interviewer and the interviewee has been positively associated—both empirically and anecdotally—with more detailed and accurate memory reports from child witnesses, adult witnesses, victims, suspects, and those interviewed in intelligence-gathering contexts (Alison et al., 2013; Almerigogna et al., 2008; Collins et al., 2002; Collins & Carthy, 2018; Holmberg, 2004; Kieckhaefer et al., 2014; Leander et al., 2009; Soufan &

Freedman, 2011). In addition to the clear upside in obtaining better information, simply engaging with contact on a personal level conveys some understanding of that person as, well, a *person*—someone with a job, activities, priorities, and so on, all of which can help the contact tracer to employ useful memory cues later ("Did you go to church that day?").

Managing the Witness's Expectations

In any interview, interviewees hold a range of beliefs and expectations about the purpose of the interview, and how their information will be used. In contact tracing interviews, these might include mistaken beliefs that will breed reluctance to report certain types of information. It is crucial that contact tracers make the objectives of the interview clear, and reassure the witness that any information provided will not be used to penalize, embarrass, or otherwise implicate anyone.

We also need to challenge interviewees' expectations about their role in an interview. When people are interviewed by authority figures, they tend to assume a passive role, waiting patiently to answer the questions asked. This "question-answerer" role might be intuitive, but it encourages the omission of critical details if those being interviewed wait for the interviewer to ask the "right" question. Instead, information-gathering interviews work best when those being interviewed—and not those doing the interviewing—are seen as the "experts." Transferring control of the interview to those being interviewed stresses the importance of their contribution, gives them autonomy, and clarifies their role as an active generator of information, and the interviewer's role as a kind of coach (Fisher & Geiselman, 1992). Transfer of control is straightforward to achieve by making it clear to index cases that they are the ones with the important information about contacts; they can help stop the spread of the virus, and therefore they should do most of the talking, rather than wait for specific questions.

Without this transfer of control and change of default expectations, index cases are unlikely to provide the level of detail that contact tracing needs. Contact tracing interviews need to extract highly-specific information from cases, but unless they are instructed otherwise, witnesses tend to describe events at a general level (Koriat et al., 2000). So although "I saw Christine at the supermarket" is not useful, explicitly encouraging index cases to shift their level of description can reveal seemingly trivial yet important details, such as "We spoke for 20 minutes and she showed me some photos of her grandson on her phone." Such a shift in this level of detail demands repeated emphasis throughout the interview in a way that maintains good rapport ("Some of my questions will feel difficult to answer because we don't usually think about our activities in this way, but keep trying your best to provide as much detail as possible").

Questions and Instructions that Promote Detail and Accuracy

In any interview, the information that we elicit is fundamentally tied to the way we elicit it. The way we frame a question has a considerable effect on the witness' response—not only to that question, but to those asked subsequently. Why? Because interviewees can unwittingly sweep information from the question into their recollection of the event in question.

For this reason, as a general rule, interviewers who need to obtain information from memory should place the highest importance on questions that don't steer witnesses towards any particular response (Home Office, 2011). Good interviewers prioritize open questions ("What happened next?"), which allow witnesses to search their own memories and decide which information to report (Fisher & Geiselman, 2010). Good interviewers also avoid leading or suggestive questions ("Did he threaten you?"), which simply ask witnesses to accept or reject information (Loftus, 1975; Sharman & Powell, 2012). Even questions that might not seem to be dramatically leading or suggestive ("Were you talking to her for more than 15 minutes?"), still provide no cues for memory processes to capitalize on—and what's worse, are associated with compromised accuracy (Fisher et al., 2000; Waterman et al., 2001). Finally, even very small changes in the framing of a question can exert significant effects on a witness's response. So "How close together were you standing?" could produce different estimates than "How far apart were you standing?"(Harris, 1973).

But although open questions maximize the accuracy of witnesses' responses, those questions rarely elicit all of the details that the interviewer needs (Gabbert et al., 2015). Even if we decide that it is worse for an index case to omit information than report something wrong, the contact tracing interviewer cannot possibly know the range of cues that might help any specific index case, which means that overreliance on a pre-determined list of questions is unlikely to generate a comprehensive set of leads. Instead, we need to help index cases to provide their own memory cues. One way of accomplishing this aim is to use *mental context reinstatement*. Mental context reinstatement is based on principle that memory is optimized to the extent that the conditions at retrieval mimic those at encoding (Tulving & Thomson, 1973). In other words, people are likely to remember more information if they are in the same context, broadly defined, as they were when they encountered that information. Although we can't ask people infected with COVID-19 to physically retrace their steps over the past week, the more they can mentally place themselves back into their past activities, the better their memories should be. This type of context reinstatement might be an instruction such as "Try to place yourself back at the church, in your mind—think about what you could see, what you could hear, how you were feeling, and so on." Instructions such as these reliably increase the information that people provide in response to open questions (Memon et al., 2010).

Even with mental context reinstatement instructions in place, however, contact tracing interviews using broad, open questions from the outset are unlikely to be successful in achieving the necessary precision for contact identification (Mosser & Evans, 2019). "Tell me about everyone you've been in contact with in the past five days" imposes too great a cognitive load and simply does not provide enough cues to encourage retrieval (a problem that will be familiar to any parents who have ever asked their child "What did you do at school today?"). A more productive approach would be to break down the period of interest into chunks of time, identifying the key locations and activities involved, and then conducting a series of "mini interviews"—one for each event, such as with the timeline technique we review later.

Use of Retrieval Support Techniques

In a contact tracing interview, an obvious way to divide the period of interest into key movements and activities is to construct a timeline for the relevant period. Memories for experiences that occur around the same time are linked together by a shared timeframe, or temporal context. This temporal context plays an important role in the memory retrieval process (Howard & Kahana, 1999; Kahana, 1996; Unsworth, 2008; Brown & Chater, 2001; Fradera & Ward, 2006). Items encoded in close temporal proximity, for example, tend to be recalled in close proximity (Polyn et al., 2009, p.130; see Kahana et al., 2008). Indeed, respondents in social, medical, and economic surveys provide higher quality information when interviewed using techniques that incorporate a temporal component to support memory—such as event history calendars—than they do in standard interviews (Belli et al., 2012; Belli et al., 2009).

Traditionally, when timelines are used, only the interviewer uses them—each temporal reference point, such as a specific date range, is a "marker" within which to frame relevant questions (Belli et al., 2001). We know, however, that the benefits of timelines are amplified when witnesses can also see and use the timeline (van der Vaart, 2004; van der Vaart & Glasner, 2007)—especially when the recall task is difficult (van der Vaart & Glasner, 2007). Because some contact tracing interviews take place by phone, then, timelines might present challenges. Though it is common to ask people to use their calendar for these contact tracing phone interviews, it would be helpful to know how well timelines work in such a medium, or the extent to which other means of remote interviewing, such as the ubiquitous Zoom, Skype, or FaceTime, might mitigate these challenges.

More recently, timeline techniques have been developed for use when interviewers need to gather information about complex events, conversational encounters, and repeated events occurring within a two-week period (Hope et al., 2013; Hope et al., 2019; Kontogianni et al., 2018). This work shows that timelines do not just help people remember what they have seen, but also help them to remember more information about the people involved and when specific events took place. In contact tracing, the timeline approach could provide the basis for a more informed set of strategies by the interviewer. For example, for each "proximity event" the index case reports on the timeline, and the obvious transitions between them ("in the office," "going to lunch," "going to the supermarket,")—the interviewer can then probe for more detail about potential interaction using open questions ("Who?" "Where?" "When?" "How long?"). Other techniques known to improve memory, such as mental context reinstatement, increase the chances of more information being recalled. Using maps for routes between locations identified on the timeline might also cue recall of incidental diversions ("Oh, I remember now—I stopped in at the newsagents on the corner on my walk home"). Encouraging interviewees to use their own diaries, calendars, appointments, reminders and other idiosyncratic planning tools or apps to construct their own timeline of their contacts might also spark recall of proximity/contact events that would otherwise be missed. In addition, feeding back cues based on interviewees' earlier responses—information about locations, social networks, or common first names—can act as powerful retrieval cues (Brewer et al., 2005). Ultimately, the goal is to cue a rich network of detailed memories of potentially relevant contacts, which are highly unlikely to be cued by the question "Who have you come into contact with the past 3 days?"

Will Technology Save Us?

Surely by now you have had this thought at least once: technology will make old-fashioned contact tracing, with all of its memory problems, a thing of the past. After all, many of us already depend on technology to mitigate the consequences of our inevitable memory failures. We don't need to remember to take our medication, leave for an appointment, or file our taxes. We need only have a phone or watch (or both) to tell us what to do and when. But in those instances, our technology prods us to do something now, or soon—in a specific location, at a specific time, or both. These are *prospective memory* tasks: they hinge on our ability to remember to perform an action in the future (Einstein et al., 2018).

By contrast, contact tracing is a retrospective memory task, and a contact tracing app therefore inherits its retrospective memory challenges. Of course you might be thinking, "My phone knows where I've been, and where other people have been—which means it also knows who I've been with." The problem is that both of those claims are only partially true. For example, your phone does not know your precise location at any given time. Location determined by cellular towers varies markedly with the load on the network, how many towers are around you, and how strong a signal you have. GPS can fare better, but its theoretical precision of 4.9 meters is under "open sky." Accuracy deteriorates near tall buildings, inside, and around trees.

Still, an effective contact tracing app need not necessarily be concerned with location—it could simply gather data about who you were with and for how long. Your phone would accomplish this task by communicating with other people's phones, and keeping a log of that information for, say, two weeks. Someone else who develops symptoms would report that to her phone, which would in turn notify all contacts, including perhaps you, and (or) health officials. Mathematical modelling suggests such an approach could "replace a week's work of manual contact tracing with instantaneous signals transmitted to and from a central server" (Ferretti et al. 2020, p. 5).

This modelling reads as optimistic in the face of the reality of how, exactly, your phone would accomplish these feats. While the most promising approach uses Bluetooth, Bluetooth creates a basket of signal detection problems (McClellan et al., 2020; MIT Tech Review, 2020). The former national coordinator for health information technology at the US Department of Health and Human Services, Farzad Mostashari, told The Verge: “If I am in the wide open, my Bluetooth and your Bluetooth might ping each other even if you’re much more than six feet away…You could be through the wall from me in an apartment, and it could ping that we’re having a proximity event. You could be a on a different floor of the building and it could ping. You could be biking by me in the open air and it could ping.” (The Verge, 2020). When everyone's phone becomes the contact-tracing version of the talking dog from the movie “Up!”—each occasionally shouting “Squirrel!”—we divert precious, limited resources away from the more efficient (albeit “old fashioned”) boots-on-the-ground approach.

Even if these contact tracing apps worked perfectly, they have limited effectiveness, thanks to the broader challenges of human behavior. For example, apps require a huge percentage of the population to adopt them. Yet Iceland, whose Rakning-C-19 (“Tracking-C-19”) app was adopted by 38% of the population—the highest uptake of such an app in the world (MIT Tech Review, 2020)—is disappointed by its effectiveness compared to that of manual contact tracing. Iceland’s disappointment might reflect the reality of basic arithmetic: even if 38% of the population installs Rakning-C-19, there is only a 14% probability that two people who pass each other both have Rakning-C-19 installed, let alone operational. That’s assuming both people are even carrying their phones.

Other approaches to contact tracing apps seem agnostic about the likely failures of prospective memory. One such approach is to gather contact details either manually or by asking people to scan a Quick Response (QR) code for everyone entering or leaving a specific location, such as New Zealand adopted. These “checkpoints would not only be created for interactions among friends, but also for public gatherings at places such as restaurants and grocery stores,” we are told, breezily (Yasaka et al., 2020, p.4). At first, we wouldn’t need to spend much effort remembering to scan the QR codes; the sheer novelty of a checkpoint would effortlessly give rise to retrieval (Einstein et al., 2005; Einstein et al., 2018). But soon enough, as the novelty wore off, the reliability of prospective memory would become heavily dependent on resource-demanding monitoring processes—and therefore difficult to sustain (Einstein et al., 2005; Einstein et al., 2018).

The reality of the world in front of us is that as businesses, institutions, and various destinations decide to enter, emerge from, or even re-enter various stages of restricted contact, we are inevitably left to manage our risks. That means in addition to needing ways we can retrospectively assess risk with contact tracing, we need ways to prospectively assess risk. Sure, there are principles worth committing to memory, such as keeping 2 meters, 6 feet, or—as Australians have been told—a kangaroo-width apart from others. But what does it mean to learn that if we reach the conventional epidemiological milestone of "two incubation periods without a confirmed case," there is low risk of the virus is actively circulating in the community? One not need identify as a Bayesian to realize that some locations and activities are probably more likely than others to be vectors of transmission for a circulating virus, and are therefore riskier (see, for example, https://corona.go.jp/prevention/pdf/en.cluster2.pdf).

Such a realization means that tackling COVID-19 requires an understanding not just about memory but about human behavior itself. And here is where technology might shine, even if it's not for contact tracing. For instance, aggregated location data can help apps, such as Google Maps, determine "peak" times during when certain locations are crowded, the density of the crowd, and how long people tend to stay. Those data, coupled with information about the type of location, and people's own reports about what they tend to do at those locations, can be woven into information about risk. So, as scientists have discovered based on US data, people don't stay long at a Subway sandwich shop—but Subways are typically small and crowded, with high turnover. And whereas your gym is less dense, people stay longer—and interact with others (Goldfar & Tucker, 2020;

https://www.nytimes.com/interactive/2020/05/06/opinion/coronavirus-us-reopen.html). But this same work shows there are also surprisingly risky locations. For example, people stay longer, and have more interaction with others, at nail and beauty salons than at sit-down restaurants. These data can help not just us, but epidemiologists and policy-makers, make more informed decisions about risk. Perhaps one take-home message is that we are all going to need to be increasingly responsive to data that documents our risk in real time while also remembering to take actions to reduce that risk. That is a difficult burden for many, especially if those have few skills to analyze and interpret those data.

Psychological science can help by carrying out rigorous, relevant scientific work about how people make decisions in the face of uncertainty, understand risk, or come to believe—and communicate—claims that just aren't true (Greifeneder et al., 2020; Tversky & Kahneman, 1974). Psychological scientists, like all scientists, should be concerned about a citizenry that might be charitably described as "underinformed" about science, and a pressing need to understand what makes for effective science communication (Olson, 2018; Scheufele & Krause, 2019). Governments and organizations can help reduce the burden by helping people understand basic principles of how COVID-19 is transmitted, and translating those principles into clear, helpful, but non-didactic messages. There is some evidence that people have responded to those messages. In the US, for example, as cases of the virus increased, people voluntarily began social distancing or putting themselves into lockdown—before the legal restrictions were put in place. Moreover, once put in place, these laws accounted for only a small fraction of the 60% drop in consumer traffic, which means most of it was a choice (Goolsbee & Syverson, 2020). But choice cuts both ways: as Anthony Fauci told the BBC, even in strictest phases of lockdown, only 50 percent of the country was ever really locked down, and so the virus was never really controlled.

Unless and until an effective vaccine emerges, then, contact tracing is the best weapon we have to fight COVID-19—and though it is true that contact tracing has been crucial in helping some countries control outbreaks, it is also true that contact tracing's Achille's heel is the fragility of human memory. But we cannot consider contact tracing or memory in isolation. When it comes to this battle, we need an understanding of the wider aspects of human behavior. And what's going to save us isn't a smart card in our wallets, or lockdown. What's going to save us is our understanding of what we need to do, why we need to do it—and our willingness to go along.

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