COVID-19 Information-Tracking Solutions: A Qualitative Investigation of the Factors Influencing People's Adoption Intention

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Numerous information-tracking solutions have been implemented worldwide to fight the COVID-19 pandemic. While prior work has heavily explored the factors affecting people's willingness to adopt contact-tracing solutions, which inform people when they have been exposed to someone positive for COVID-19, numerous countries have implemented other information-tracking solutions that use more data and more sensitive data than these commonly studied contact-tracing apps. In this work, we build on existing work focused on contact-tracing apps to explore adoption and design considerations for six representative information-tracking solutions for COVID-19, which differ in their goals and in the types of information they collect. To do so, we conducted semi-structured interviews with 44 participants to investigate the factors that influence their willingness to adopt these solutions. We find four main categories of influences on participants' willingness to adopt such solutions: individual benefits of the solution, societal benefits of the solution, functionality concern, and digital safety (e.g., security and privacy) concerns. Further, we enumerate the factors that inform participants' evaluations of these categories. Based on our findings, we make recommendations for the future design of information-tracking solutions and discuss how different factors may balance against benefits in future crisis situations.

CCS Concepts: • **Computer systems organization → Human Computer Interaction (HCI)**.

Additional Key Words and Phrases: Usable privacy and security, information sharing, data practices

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1 INTRODUCTION

Numerous digital information-tracking tools have been implemented worldwide to trace and slow the spread of COVID-19. The most commonly discussed are contact-tracing apps, which notify users if they have come into contact with someone who is COVID positive. According to the data compiled by Top10VPN [158], 120 contact-tracing apps have been launched worldwide in 71 countries and regions. Meanwhile, in addition to contract-tracing apps, many other COVID-related digital tracking measures are active in 38 countries. For instance, Australians' *location data* have been used by the government, medical experts, and the media through a transport app (i.e., CityMapper), that shows how

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people move through cities in an attempt to determine whether people's movement has reduced [54]. People who have received an order to quarantine in Moscow are required to send a *selfie* several times a day, through a monitoring app, to confirm that they are self-isolating [103]. These digital tools make use of people's information (e.g., location data, selfies, and phone numbers) to conduct digital tracking with the end goal of helping slow down the spread of COVID-19. We collectively refer to these digital tools as *"information-tracking solutions."*

Previous studies have mostly focused on contact-tracing apps. As contact-tracing apps are the most popular digital tool used worldwide to fight against COVID-19 [158], most previous work has emphasized investigating the public's attitudes toward these apps [28, 91, 97, 106, 130, 133, 145, 154]. Specifically, many factors that could potentially influence the public's intentions to adopt contact-tracing apps have been identified, including technological benefits, perceived barriers, privacy concerns, accuracy concerns, individual differences, and app data architectures [3, 4, 9, 14, 60, 65, 74, 79, 84, 115, 122, 126, 137, 144, 147, 148, 161].

However, there is a lack of understanding of the factors that influence people's willingness to comply with various information-tracking solutions beyond contact-tracing apps. As there is no single canonical solution that can achieve various tracking goals, governments worldwide have implemented multiple measures simultaneously to control the pandemic and reopen the economy [158]. For example, the South Korean Ministry of the Interior launched the "Self-Quarantine Safety Protection" app to monitor people who are quarantining [33]. Meanwhile, a data-analysis platform was launched to enable tracers to identify the transmission routes and places that a COVID-19-positive (in this paper, designated "C-positive") person has visited [139]. These information-tracking solutions have diverse goals, such as identifying close contacts of a C-positive person, monitoring social distancing [120], and enforcing quarantine [33, 56, 63, 68, 92, 103, 110, 129, 136]. To achieve these tracking goals, solutions may require users to provide various types of data, such as their names [12, 45], location data [11, 52, 102, 114], and phone numbers [1, 12, 50, 102]; not all information is required for the contact-tracing solutions that have been heavily investigated. Therefore, it is necessary to explore people's perceptions of this wider spectrum of information-tracking solutions that require different types of personal information from users and achieve different tracking goals.

Through 44 interviews, we identified the following four main categories of influences on participants' willingness to adopt information-tracking solutions: individual benefits of the solution; societal benefits of the solution; functionality concerns; and digital safety concerns. Furthermore, we report the factors that inform the participants' evaluations of these categories. Based on our findings, we suggest that future information-tracking solutions should focus on the above four aspects. Trust in various solution providers should be built and maintained. Additionally, methods should be adopted to ensure that the individual benefits of a solution are actually provided. Furthermore, the effort required to implement the solution should be minimized. Finally, solution providers could highlight the often overlooked societal benefits of the solutions.

2 BACKGROUND AND RELATED WORK

2.1 Various Information-Tracking Solutions

Contact-tracing apps play a vital role in helping health authorities identify people who may have been exposed to the virus [158]. Based on the data collected to facilitate contact tracing, contact-tracing apps' data can be classified into the following three types: cell phone base station data, location history [69, 95, 113], and Bluetooth proximity data [1, 12, 15, 50, 51]. Based on the data structure, contact-tracing apps can be further classified into centralized approaches and decentralized approaches. In a centralized architecture, contact tracing is performed using a centralized

server that requires C-positive users to upload their contact log to the server, which then performs the exposure detection. In contrast, the decentralized architecture allows the exposure to be detected on users' phones by downloading C-positive users' data from a central server. Many researchers proposed decentralized infrastructure for contact-tracing apps, such as DP-3 [138], PACT [118], and TCN-protocol [41]. Moreover, Apple and Google released a framework, named "Exposure Notification (GAEN) System," to facilitate digital contact tracing [47]. Many apps, such as COVID Alert [51], have been developed based on this platform.

Meanwhile, many other solutions have been implemented to prevent the virus from spreading further and to reopen the economy. For instance, many methods have been used to enforce home quarantine orders [33, 56, 63, 68, 70, 92, 103, 110, 129, 136], such as electronic bracelets [63, 92], apps requiring selfies [68, 103], and apps that verify users' locations [33, 136]. Moreover, as a strategy to stay open, many shops and restaurants ask customers to provide their contact information to allow them to be traced in case someone found to have the virus was present at the same time [107]. Another proposed strategy is immunity passports [22], which have provoked significant debates regarding effectiveness, equality, and racism [16].

2.2 Risks of Information-Tracking Solutions

Many studies have identified the privacy and security risks linked to various information-tracking solutions. Through the analysis of contact-tracing apps, many privacy risks have been identified, including apps that have no publicly stated anonymity measures [158, 162], apps that expose identifiable information [150], and apps that collect personal information (e.g., users' names) [13, 40, 61, 78]. For instance, out of 73 digital health certificate apps, 36 do not disclose what types of personal identifiable information they collect from users, 59 do not disclose whether they retain data collected from users, and 42 share data with third parties [158]. Cho et al. [27] analyzed Singapore's TraceTogether App and identified three types of privacy relevant to this app, including privacy from snoopers, privacy from contacts, and privacy from the authorities. Casagrande et al. [24] analyzed eight contact-tracing apps that have been implemented worldwide (e.g., Immuni [152]) and found that all of them were vulnerable to relay attacks. Several studies [5, 81] revealed that no technological solution can provide effectiveness, privacy guarantees, and freedom from cyber-attacks. For example, centralized systems may put the privacy of all users at risk, while decentralized systems tend to place the privacy of C-positive users at risk.

2.3 End-User Studies

Many user studies have been conducted to explore the factors that the public considers when deciding whether to use a contact-tracing app. The perceived benefits [20, 49, 74, 86, 100, 115, 146, 147, 156], solution accuracy [74, 115], privacy considerations [3, 4, 65, 74, 115, 154, 161], security concerns [3, 83], efficacy concerns [10, 36, 65, 98, 111, 143, 147], perceived stigma [72, 154], personal health conditions [55, 101], and mobile-related costs [65, 115] are common factors identified in previous quantitative studies. Kaptchuk et al. [74] further investigated how different benefits, privacy decisions, and accuracy levels affect the public's perceptions of a contact-tracing app. The results show that 75% to 80% of people would consider installing a perfectly private and accurate app.

2.4 Technology Acceptance Model

People's decisions regarding the acceptance or rejection of new technologies have been extensively researched. Numerous theories have been proposed to explain users' behavior in relation to technology adoption, including the technology

acceptance model (TAM) [31], diffusion of innovations theory [119], and the unified theory of acceptance and use of technology [141]. As the best-known approach, the TAM has been examined, expanded, and applied to many domains, such as online shopping [142], implicit authentication on smartphones [94], and mobile health apps [17, 26, 35, 96, 108, 163]. For instance, based on the TAM, Miao et al. [96] studied the key factors that influence users' mobile health adoption intentions. Their results suggested that perceived usefulness, perceived ease of use, subjective norms, the existing degree of satisfaction, and network effects impact users' adoption intention.

Our study differs from prior studies in two ways. First, instead of focusing on contact-tracing apps, we investigated people's perceptions of six different information-tracking solutions that are currently used worldwide to fight COVID-19. Our results could inform the future design of similar solutions with varying tracking goals that require different types of information from participating users. Second, our qualitative approach enabled us to explore various factors that participants consider when deciding whether to use a given solution. Furthermore, we acquire a deep understanding of participants' reasoning when considering certain factors, how one factor motivates/hinders different participants from using solutions, the factors that participants consider when interpreting different solutions, and how these factors relate to one another.

3 METHOD

3.1 Data Collection

The participants were recruited by advertising on Facebook, Twitter, Reddit, Kijiji, and our institution's participant study list. We conducted the interviews via Zoom between May 12, 2020, and January 4, 2021. We used a screening survey to select a diverse sample in terms of age, occupation, and education (see the screening survey in the supplementary file). Participants were compensated with either a $25 Amazon gift card or an e-transfer [153]. On average, the interviews lasted 54 minutes. This study was approved by our institution's research ethics board.

3.2 Information-Tracking Solutions

We presented six different solutions to the participants. Our main purpose was to explore participants' perceptions of a wide range of solutions. These solutions were selected based on *their different tracking goals* and the *different types of information* collected from and about their users. We developed solution descriptions that closely matched the solutions' actual implementations (as explained on official government websites (e.g., [51]) and online articles (e.g., [68])) while keeping the descriptions independent from the actual implementations. Additionally, to avoid biasing participants, we only described the essence of the solutions (e.g., information collected, purpose of the information collection, and main functions), but did not mention the country in which each solution was implemented or whether a given solution was voluntary or mandatory. Next, we described the six solutions presented to the participants (check the supplementary file for more details).

Home quarantine app (*HQ-app*). A home quarantine protocol is intended to promote social distancing and thus reduce the number of infections. We created the home quarantine app description based on several existing solutions (e.g., apps required for Polish residents who are under mandatory 14-day quarantines after returning from abroad [68], patients and their family members in Moscow [66, 103], and people quarantined in the Indian state of Karnataka [34]) that collects users' *selfies* and *location data*.

Epidemiological investigation support system (*EIS-sys*). Investigation, classification, tracking, and management of contacts by identifying the C-positive person's routes are critical for preventing the transmission of an infectious

disease. However, omissions and errors often occur when tracers interview C-positive people [43]. To overcome these limitations, methods that can objectively verify the C-positive person's routes have been used [76, 139]. Based on existing methods (e.g., [139]), we developed a description of a generic epidemiological investigation support system that uses a C-positive person's *location data, credit card transaction history, and CCTV recordings* to verify their past contacts with others.

Centralized and decentralized contact-tracing apps (*CCT-app & DCT-app*). Although many previous studies have investigated contact-tracing apps, we include such apps as a comparison point for other solutions, with a consistent set of participants. We created two contact-tracing app scenarios that differed based on the app's use of a centralized or decentralized proximity-based architecture. The description of the centralized version was based on several existing apps that require users to provide their *phone numbers* to receive exposure notifications (e.g., apps used in Alberta, Canada [50], Singapore [1], and Australia [12]). The description of the decentralized version was based on examples from Canada [51], Switzerland [32], and Germany [151].

Information tracking of dine-in customers (*DineIn-sol*). As COVID-19 restrictions ease and restaurants begin to welcome customers, methods to assist in contact tracing in the event of an outbreak have been established [105]. For instance, restaurants are required to collect customers' contact information in Canada [53], Germany [75], and Australia [88]. Specifically, customers may be asked to provide their *names and phone numbers along with their check-in and check-out times* [30], through a visitor management app [125] or by scanning a quick response (QR) code [39].

E-permit service (*EP-svc*). Governments and businesses have slowly begun to reopen the economy and loosen restrictions. As one strategy, digital travel permits [8] or health certificates [22, 112, 121] can enable citizens to travel while avoiding COVID hotspots. Moreover, with the availability of vaccines, technology and health companies have joined efforts to create a new standard for COVID vaccine certification, which has been used for travel [25, 85, 127, 128, 164]. We used these examples to develop a description of an e-permit solution that requires users to provide their *health status* and *trip information*.

3.3 Interview Procedure

We asked participants to provide feedback regarding each solution. During the Zoom interviews, the lead researcher shared their screen to display the descriptions of the six solutions. Then the participants were informed that they were welcome to ask for clarification regarding the descriptions. The order of the solution descriptions was randomized across the participants. During the semi-structured interviews, we asked open-ended and major questions to facilitate in-depth discussion with the participants [37, 99]. Specifically, after a participant read each solution description, they were asked to share their perceptions of the solution. Then researchers asked questions regarding the aspects of the solution that the participant liked or disliked, and why. Following the participants' responses, the researcher sometimes asked additional questions to better understand their reasoning. For instance, if the participant voiced a concern, we asked them to explain the aspects of the solution that they were concerned with and the reasons for their concern. If the participant did not mention certain elements of the solution, we asked guiding questions regarding their thoughts about each type of information required to use the solution and their preferred data practices. See the interview guide in supplementary file for more details.

3.4 Data Analysis

We followed an iterative and qualitative open-coding process based on a grounded theory approach [29, 46, 93]. After each interview, two researchers independently analyzed the collected data using the NVivo tool [104]. Then, the two

Categories influencing adoption	Factors influencing participants' adoption intention		*EP-svc*	*DineIn-sol*	*CCT-app*	*DCT-app*	*HQ-app*	*EIS-sys*
Individual benefits	Workload burdens of obtaining individual benefits		✓	✓				
	Perceived erosion of own benefits when others misuse the solution		✓	✓				
	Exposure notifications being provided by nonprofessionals		✓	✓	✓	*		
	Unnecessary psychological burden of false alarms		*	*	✓	✓		
Societal benefits	Reluctance of users to notify exposed users				✓	✓		*
	Lack of individual benefits				✓	✓	✓	✓
	Mitigation of others' dishonesty						✓	✓
	Assumption of being irresponsible						✓	✓
	Waste of public resources						✓	✓
Functionality concerns	Technology limitations				✓	✓	✓	
Digital safety concerns	Privacy concerns about the **information** required by solutions	Location data	✓				✓	✓
		Selfies					✓	
		Phone number	✓	✓	✓		✓	
		COVID-19 test status	✓					
		Credit card transaction history						✓
		CCTV recordings						✓
	Privacy concerns about the **data practices** of solutions	Data collection	✓		✓	✓		
		Data usage	✓	✓			✓	*
		Data retention					✓	
		Data sharing	✓	*				
	Security concerns	Threat of identity theft						✓
		Threat of re-identification		✓	✓			
		Threat of scams	✓		✓	✓	✓	
		Threat of data breach					✓	
	Solution providers	Govt. & health authorities	△	△	△	△	△	△
		Technology companies	△	△	△	△	△	△
	Violations of human rights		✓				✓	
	Perceived main benefits of solutions		Perceived more benefits to individual		Perceived benefits to both individual and society		Perceived more benefits to society	

Table 1. Participants' perceived benefits of information-tracking solutions. Symbols: ✓indicates that the participants consider certain factors when deciding whether to adopt the solution; △ indicates that certain factors could motivate some participants to use the solution while discouraging others; and * indicates that the results were inferred. Factors with a gray or blank background indicate that the factors can motivate or discourage participants from using the solutions.

researchers met to discuss whether there were interesting codes or data gaps that could be explored in depth. If so, they modified the interview guide accordingly [123]. To measure inter-coder reliability, we calculated the average percentage of agreement of all codes between the two researchers who independently coded all interviews. The result was 88%, indicating a high level of agreement between the two coders. Theoretical saturation was reached after 35 interviews (see saturation graph in the supplementary file) and we interviewed an additional nine participants to confirm that no new codes would appear. Similar to many qualitative studies that used grounded theory [2, 23, 67, 117, 149], we performed open, axial, and selective coding to analyze data. During open coding, 606 codes were identified. As axial coding requires researchers to continually modify, reshape, and connect the emerging categories [124], six researchers with various research backgrounds (besides background in human computer interaction) engaged in a code and theme sorting exercise to reach a consensus concerning the identification of eight themes. Later, all authors worked together to select the core category and relate it to the other categories. The categories that were not related to the core category are omitted from this paper.

4 RESULTS

4.1 Participants

We performed semi-structured interviews with 44 participants who live in Canada. Their ages ranged from 19 to 71 years, with an average age of 41 years and a median of 40 years. Twenty participants were female, 23 were male, and

one was a transgender man. Eight participants held a high school diploma as the highest level of education achieved, 6 held a community college diploma, 22 held a bachelor's degree, 6 had a master's degree, and 2 had a PhD. Twenty-seven participants were recruited via a Facebook advertisement, 10 learned about this study from our institution's paid study list, 3 heard about it from a friend/family member, 2 saw our advertisement on Reddit, and 2 saw our advertisement mentioned on Kijiji. Regarding previous experience with the presented solutions, none of the participants had used the *HQ-app*, *EIS-sys*, or *EP-svc*. Twenty participants were using a *DCT-app* at the time the interview was conducted. Further, 3 participants had used a tracking solution similar to *DineIn-sol* before. Participants' detailed information is summarized in the supplementary file.

We classified our findings into four categories associated with participants' willingness to adopt the presented solutions and we further report the factors influencing the participants' evaluation of these categories (categories and factors are summarized in Table 1).

4.2 Perceived Benefits of the Solutions

Perceived benefits serve as motivation to adopt an information-tracking solution. Similar to the findings in many studies [4, 74, 83, 115, 147, 154], we find that participants perceive the solutions as providing benefits to themselves as individuals, benefits to society, or both.

EP-svc and *DineIn-sol* were believed to bring **more individual benefits**. For instance, participants valued enabling people to travel as the main benefit offered by *EP-svc*. As explained by P11, *"If you have this ticket, saying that ... your health status is fine, then you are safe to [go] everywhere without any restrictions."* The perceived main benefit offered by *DineIn-sol* was to allow customers to enjoy dine-in services and receive notifications if they are exposed to a C-positive person.

The two types of contact-tracing apps (*CCT-app* and *DCT-app*) were perceived as bringing **both individual and societal benefits**. Participants liked the apps' feature of allowing them to receive a phone call or notification if they were found to have been exposed to C-positive people. They believed that being notified of an exposure would allow them to start monitoring their symptoms, get tested, and obtain treatment sooner. Participants also appreciated the societal benefit of the apps: helping prevent the virus from spreading further. For instance, participants noted that users who are C-positive can upload their contact logs through the app, triggering the detection of exposures and the notification of other users.

HQ-app and *EIS-sys* were viewed as providing **more societal** than individual benefits. Most participants believed that *HQ-app* provides a way to enforce quarantine, which can help slow the spread of COVID-19. For example, P2 remarked, *"[HQ-app] is really good because it makes sure that no one breaks [their quarantine] and people actually do the 14 days; then, everybody else will be safe."* By combining information from multiple sources, *EIS-sys* was also believed to provide more societal benefits by providing detailed routes of a C-positive person, enabling health authorities to identify the path of virus transmission and infection clusters.

4.3 Factors Linked to Individual Benefits

We identified four factors that influence the participants' perceived individual benefits of the solutions (see Table 1).

Workload burdens of obtaining individual benefits. Perceived great efforts to obtain individual benefits reduce the benefits. *EP-svc* and *DineIn-sol* were considered to provide great individual benefits, such as enabling travel and allowing customers to enjoy dine-in services. While appreciating these benefits, the perceived workload to obtain these benefits eroded participants' perceived level of benefit. For instance, requiring a permit with *EP-svc* for every trip was

perceived as too much of a hassle for people: *"But to use [the E-permit service] for every single trip would be a lot of work for people who want to travel."* (P1). Similarly, several participants believed that *DineIn-sol* required considerable effort if customers have to provide their information every time they visit a restaurant.

Perceived erosion of individual benefits when others misuse the solution. Participants suspected that other people might provide false information when using the presented solutions, which in turn decreases their individual benefits. For instance, P20 argued that people might lie about their health status (*EP-svc*) to board a plane (which has been confirmed by the news [135]) and stated: *"I think the potential for lying is quite possible. You could definitely lie and say that you tested negative."* Participants also expressed concerns about other people providing false information to enter a restaurant (*DineIn-sol*), which would reduce their own benefits, as it would prevent contact tracing from being properly performed.

Exposure notifications provided by nonprofessionals. Having unqualified people contacting users to provide notifications of exposure was perceived to decrease individual benefits. Being notified of possible exposure was perceived as a great individual benefit of *CCT-app*, *DineIn-sol*, and *EP-svc*. Moreover, participants preferred the message notifying of possible infection to be delivered by people with medical training (e.g., employees of health authorities). Therefore, people who receive the message would take it more seriously and follow the suggested guidelines more accurately. However, some participants believed that unqualified people might perform the notifications, thereby decreasing the individual benefits: *"I do not want Burger King to phone me up and tell me that I have to get tested. I'd like to be notified by health officials"* (P15).

Unnecessary psychological burden of false alarms. Some participants noted that being exposed does not mean being infected. Therefore, a notification of exposure may impose an unnecessary psychological burden on exposed users and result in unnecessary quarantine. For example, P20 disliked *DCT-app* and explained her reason as follows: *"I think it would cause a lot of alarm for some people. But you do not even know if [the exposure is] confirmed."*

4.4 Factors Linked to Societal Benefits

We identified five factors associated with participants' perceived societal benefits of the solutions (see Table 1).

Reluctance of users to notify exposed users. The psychological burden on C-positive users might reduce their willingness to notify others. Several participants imagined that having COVID-19 would be hard enough for a C-positive person to bear. Further, giving notification through the *CCT-app* or *DCT-app* to the people that they had exposed would place a psychological burden or a sense of guilt on a C-positive person. Hence, a C-positive person might decide not to use the solution to notify exposed users, reducing the solutions' societal benefits. To illustrate, P8 stated: *"You already have a disease, but now you have [the] additional feeling that, 'Oh. I have infected other people.' For me, it is really scary."*

Lack of individual benefits. Participants were hesitant to use the solutions that did not seem to provide any individual benefits. While P41 acknowledged that *HQ-app* can benefit the community by preventing the virus from spreading (i.e., societal benefit), he showed no interest in using it due to the lack of personal benefits. To illustrate, P41 remarked: *"It does not give me any benefit. So I do not see any reason why I would use it."* Even contact-tracing apps were not always deemed to directly benefit their users. For instance, P15 questioned whether *CCT-app* or *DCT-app* would benefit him because he took precautions (i.e., practiced social distancing) when around others. He believed that he would not come into close contact with C-positive people: *"If my wife and I go out for a walk and there is somebody coming, we would let them pass so that we do not come within six feet, right?"*

Mitigation of others' dishonesty. Believing that others may cause damage to the community by being dishonest, participants showed interest in the solutions that aided compliance enforcement and the investigation of infection

sources. Many participants knew of others (personally or through the news [59]) who did not comply with quarantine orders. Therefore, they showed interest in *HQ-app*, which could aid in quarantine enforcement. P30 explained: *"I know there has been a lot of people who do not quarantine properly, obviously do not abide by the rules. So I think it would be good to have at least something that could be enforced."* Moreover, believing that C-positive people may lie or withhold information out of self-interest, participants saw a need for *EIS-sys*. P26 stated: *"I am sure [EIS-sys] would be more accurate and provide more information about where and how the virus is spreading. And definitely not putting it in the patients' hands, whether they report it or not."*

Assumption of being irresponsible. In contrast to the previous sentiment, some participants argued that the solutions were designed based on the assumption that people are generally irresponsible and place the community at risk. Therefore, they cited stigmatization as the main reason for their unwillingness to adopt *HQ-app* and *EIS-sys*. For instance, P3 argued that people should be presumed trustworthy in following quarantine orders and compared *HQ-app* with house arrest. She further stated: *"[HQ-app] is criminalizing normal people who are not criminals."* Moreover, P13 believed that CCTV recordings (*EIS-sys*) should only be used to spot criminals. Using it to check and verify C-positive people's activities suggests that *"[C-positive patients] did something wrong"* (P13).

Waste of public resources. Some solutions require many public resources, which participants considered a great cost that offset the solutions' societal benefits. For instance, participants argued that it would be a waste of resources for police officers to pay a visit every time a user failed to provide a selfie through *HQ-app*. Participants noted that there might be situations when people fail to upload a selfie without interrupting their quarantine, such as being in the shower. Further, a few participants indicated that checking every C-positive person's activities through *EIS-sys* was also a waste of public resources. For example, P40 stated: *"If you have an agent spend all the efforts to track down one [C-positive] person, it would be a waste of resources, especially [when] we have 500 cases."*

4.5 Functionality Concern

Technology limitations. Participants raised concerns about the limitations of the technology used in the solutions, which led them to question the effectiveness of the solutions. For instance, by referring to the news they read (such as [38, 71, 155]), participants believed that the facial recognition technology (used in *HQ-app*) might misidentify certain types of people (e.g., people of color) or people wearing masks. Participants also believed that this technology has a high rate of errors: false positives and false negatives [155]. To illustrate, P7 commented on the technology: *"There is a big chance of mistakes for people of color."* Moreover, the accuracy of using Bluetooth to approximate distances between two phones (*CCT-app* & *DCT-app*) was questioned by participants (which is confirmed in a recent study [132]). For instance, P16 stated: *"I am just wondering how accurate the app would be, like the false positive rate."*

4.6 Digital Safety Concerns

We categorized the last group of factors that influence participants' willingness to adopt the solutions as digital safety concerns. Based on previous work [116], we define digital safety concerns as encompassing privacy and security concerns and other issues related to digital considerations (e.g., solution providers). Further, we report the factors that inform participants' evaluation of this category.

4.6.1 Information required to use the solution. Privacy concerns over the information needed by the solutions are associated with participants' unwillingness to adopt the solutions. Participants were reluctant to share their private information, such as their location information, credit card transaction history, video recordings [83, 130, 161], selfies,

and COVID-19 test status. In particular, many participants were concerned about uploading selfies to *HQ-app*. For example, P16 argued that as a type of biometric information, face recognition is extremely private and should only be accessible under certain protocols, such as by a court order. Citing health-related information as sensitive and personal, P21 did not want to reveal her COVID-19 test result to use *EP-svc*: *"My [health status] should [be shared] between my doctor and me. Having to provide the information to use* EP-svc *is really invasive."* Considering phone numbers as personally identifiable information, several participants did not like the idea of sharing such information to use the solutions. For instance, P19 explained her concern as follows: *"My mobile phone number is the same number that I use for my health card [and] for my address. It is not going to take too long for [the government] to reverse."* Similar to the findings in [83, 130, 161], our participants were also uncomfortable with the use of their credit card history, location data, and surveillance camera footage for contact tracing.

4.6.2 Solution data practices. Data practices of the solutions were an important factor for participants. Their concerns regarding data practices were found to be related to data collection, data usage, data retention, and data sharing.

Covert collection of personal data. Participants were concerned that the solutions collect more data than they claim to. P8 distrusted *CCT-app* and expressed her concern as follows: *"I believe, even though [the app developers] say that they use only your mobile phone number. [The government] would find a way to use other private data; like, your location is traced."* In addition, several participants worried that further health-related information (e.g., having a disability) beyond their COVID-19 status might be used to determine their qualifications for traveling (*EP-svc*). To illustrate, P9 stated: *"But what if other things are added to the list of conditions that suddenly I am not allowed to travel? ... I have a disability. So, I can imagine my health status may be considered not up to some sort of muster."*

Use of the collected data for other purposes. Participants worried that the collected personal data might be used for purposes other than to control the COVID-19 pandemic. By priming participants, Li et al. [83] discovered that the risk of the secondary usage of data significantly reduced the adoption intention of contact-tracing apps. While our findings confirm their results, we further explored the types of secondary usages that the participants were worried about. Specifically, several participants suspected that restaurants might use customers' information to deliver promotions (*DineIn-sol*): *"My contact information might be reused for advertising, like sending me promotions"* (P18). Some participants raised a similar concern regarding their selfies being used for advertising. (*HQ-app*): *"Selfies might be used for advertising purposes"* (P7). Additionally, participants were worried that their information might be used for post-pandemic purposes. To illustrate, P13 stated: *"It is like you are under control all the time, like after the pandemic. If you have suspicious symptoms, you are always worried that somebody has your phone number and location and could use your information to force you to stay at home."*

Abuse of personal data in the long term. Participants expressed concerns about their personal data being abused in a long term. For example, P17 compared the selfies required by *HQ-app* to undergoing genetic testing, and further explained: *"I can change my phone number. I can move all around the world with my location and feel okay, but I cannot change my facial recognition. So that worries me ... you can theoretically be monitored for the rest of your life."*

Unauthorized sharing of data. Participants expressed concerns about their data being shared with other organizations without their permission. For example, after being asked to further explain the concern of credit card information being shared with other entities in *EIS-sys*, P16 raised an example of a solution provider profiting from this information: *"Like real estate companies send me targeted ads based on my expense or merchants send me promotional emails based on my previous purchases."* Because multiple types of personal information (e.g., health status and trip information) are needed for users to apply for *EP-svc*, participants were concerned that their information would be sold by irresponsible

data handlers. For example, P21 explained his concern: *"I think your information will end up in the black market. Because that is personal information, people will find a way to make money out of it."*

4.6.3 Security concerns. Participants' unwillingness to adopt the solutions was associated with their security concerns.

Threat of identity theft. P20 expressed unwillingness to provide her credit card information in *EIS-sys* due to concerns about identity theft: *"Credit card transaction history is a little bit [of] a red flag because that could open up so many issues, like identity theft."*

Threat of re-identification. Several participants were concerned that their phone numbers may be leaked and used to identify them (through *CCT-app* or *DineIn-sol*). Contrary to the concern about C-positive users being re-identified [83], our participants were worried that their information may be leaked, allowing for re-identification. To illustrate, P26 said: *"If you put a person's phone number on LinkedIn, you can find out who that person is."*

Threat of scams. A few participants argued that people who are eager but are not eligible to apply for *EP-svc* might become victims of related scams. P16 explained in detail the scams that he believed could arise: *"As plane tickets are pretty expensive right now and people are eager to travel, I believe that criminals could take this as an opportunity to scam people."* Moreover, being notified of exposure was perceived by participants as a great benefit of the solutions *CCT-app* and *DineIn-sol*. However, they believed the caller should be verified to prevent users from being scammed. For example, P40, who received a call from health authorities as she recently traveled back from overseas, questioned the identity of the caller: *"What if that was a random person [who] was collecting information? It could be a scam call, right?"*

Threat of data breach. Participants believed that the personal data collected by the solutions could be targeted by criminals. For instance, P5 noted his concern about *HQ-app* as *"There would be people who would try to hack the app to get your geolocation and your photos. I think it would be huge on a hacker's priority list."*

4.6.4 Solution providers. Our results suggest that solution providers play a factor in influencing adoption intentions. Specifically, solutions operated by trusted entities motivate participants to consider using the solution. However, having concerns about solution providers negatively affects participants' adoption intentions. Our participants identified the following two solution providers.

Government and health authorities. Most participants were very comfortable with the health authorities and the government as the solution provider (similar to previous studies [83, 86]). We further explored three factors affecting the participants' trust toward the government and health authorities:

Performance during the pandemic. Believing that the government and health authorities performed well during the current pandemic led the participants to trust the solutions provided by the government. For example, P4 preferred using the solutions promoted by the government and explained her reasons as *"Because looking at how Canada has performed and how professional our health authorities are."* Meanwhile, being dissatisfied with the governments' performance during the pandemic, participants tended to distrust the solutions it provided: *"I do not trust Québec government updates. For example, they will say this is the number of people who have died on a daily basis. And almost every day, they make a correction"* (P19).

Transparency with the public's data. When believing the government is transparent regarding how it handles the public's data, the participants were favorable to the idea of the government being the solution provider. For example, P5 commented on the government being the solution provider as follows: *"As long as [the government] is transparent about why they need the information from people and what the information is for."*

Prior positive experience with the government. Some participants' trust in the government was based on their long-term experience with it. P15 explained: *"From my experience, the Canadian government is pretty good. I feel like generally people are looked after and their rights are being respected and I do not feel like I am at risk."*

Technology companies. Technology companies were preferred as solution providers by some participants while disliked by others. Having faith in big technology companies' ability to protect users' privacy led some participants to prefer such companies as solution providers. For instance, P11 remarked his preferences as *"a trustworthy company, like a high technology company that can protect people's privacy ... like Google."* However, some participants disliked the technology companies acting as solution providers. They expressed concerns that such companies use users' data for their own ends, such as advertising. Additionally, participants questioned the companies' ability to protect users' data: *"So many companies have [suffered data breaches] over the years"* (P5).

4.6.5 Violations of human rights. Participants expressed reluctance to use *HQ-app* and *EP-svc* due to their concerns that these solutions violate human rights of freedom of movement and equality. For instance, a few participants commented that *HQ-app* might violate users' human right to *freedom of movement*: *"I think* HQ-app *is a complete infringement on our rights as human beings"* (P3). A few participants believed that they should have the right to travel without restriction and therefore expressed reluctance to use *EP-svc*. Furthermore, several participants believed that *EP-svc* might lead to discrimination, as people might be categorized into two groups: those who are allowed to travel and those who are not. Hence, they considered this service a violation of the human rights to *equality*. To illustrate, P4 stated: *"[HQ-app] can lead to discrimination, giving people labels, like you are OK to travel and [others] are not."*

5 DISCUSSION

5.1 Complex Decision-Making Process

Participants' willingness to adopt the solutions was associated with many factors. Instead of making a simple privacy-utility trade-off [84, 115], participants considered many other factors when deciding whether to adopt the solution. Specifically, each perceived (individual or societal) benefit could motivate the participants to be interested in the solution (Section 4.3 and 4.4). Alternatively, each identified concern could serve as a deal-breaker (Section 4.5 and 4.6).

One of our contributions is extending and placing the findings of previous studies regarding past pandemics into the context of the COVID-19 pandemic. Prior research has identified many factors linked to the adoption of contact-tracing apps in the context of past pandemics and health-related apps: human rights [80, 89, 90], privacy and security considerations [48, 82–84, 86, 154], concerns about stigma [154], perceived benefits [74, 115, 147], perceived reliability [7], performance expectancy [7, 157], and social influence [7]. Building on prior work, we place our identified factors in the context of various information-tracking solutions for managing the COVID-19 pandemic. For instance, in contrast to the concerns about the denial of healthcare services to HIV patients [90], our participants' concerns about human rights were related to freedom of movement and equality (Section 4.6.5). Regarding the HIV/AIDS pandemic, concerns about stigma are related to morally blaming those infected with HIV/AIDS [90]. However, in our study, the perceived stigmatization of the solutions was related to concerns that users would be treated like criminals (Section 4.4).

Based on our comprehensive exploration of participants' thoughts about adopting different information-tracking solutions, we recommend that **future solutions focus on four main aspects: individual and societal benefits, functionalities, and digital safety** (**Recommendation 1**). As the benefits of the solutions serve as great motivations for participants to consider the solutions (Section 4.4 and 4.3), efforts should be exerted to help people better understand and appreciate the solutions' benefits (see our detailed recommendations in Section 5.3). Compared to quantitatively

identified privacy and security concerns about contact-tracing apps [3, 4, 65, 74, 83, 115, 154, 161], we further discovered that participants' concerns are associated with *solutions' data practices and their providers* (Section 4.6). Regarding data security, in addition to the previously identified concerns about C-positive people being re-identified, we discovered four more concerns (Section 4.6). Therefore, future solutions could focus on configuring the above aspects of the solution (e.g., data practices of the solution) and, more importantly, on clarifying the solution to the public (Section 5.2). Further, we discovered concerns about solutions' functionality (Section 4.5). Therefore, we suggest that future solutions to also explain their limitations (e.g., the success rate of the solution) to help potential users better manage their expectations.

5.2 Two-Sided Factors

The identity of the solution provider can be a factor that motivates some people to adopt a solution while discouraging others. For example, commercial organizations could be supported by some users and disapproved of by others. In addition to expressing whether they trust the technology company with their data [58, 134], our participants considered the company's ability to protect the data, and having faith in certain technology companies' ability to protect users' privacy seems to be positively correlated with adoption intention. Other participants, however, were concerned about the possibility that a commercial provider might attempt to profit from users' personal data. As a result, they were reluctant to use the solutions provided by commercial organizations (Section 4.6.4). This is an example of a "two-sided" factor that might motivate some users and discourage other users.

Government and health authorities are not necessarily the perfect solution providers. As reported in many previous quantitative studies [9, 57, 115], people who trust their government and health authorities were more likely to install a contact-tracing app. While our results echo these findings, we further discovered that participants' trust in the government and health authorities as providers of solutions for managing the COVID-19 pandemic depends mostly on whether the individuals approve of the government's handling of the pandemic and public data (Section 4.6.4).

Recommendation 2: Build and maintain trust in solution providers through transparency. Providing transparency could help build trust in various solution providers. Previous studies suggest that trust could be less important during a global pandemic, when the public might be more willing to accept situations (e.g., privacy violations) that they would otherwise reject [57]. Our results suggest, however, that trust in solution providers appeared to be positively associated with participants' adoption intentions of information-tracking solutions. Specifically, participants' trust in the government being the solution provider was mainly linked to its performance during the pandemic and its management of public data. Hence, to maintain public trust in the government and its agencies, we suggest that governments be transparent and direct with their pandemic strategies [19, 42]. For instance, the government's pandemic responses (e.g., requiring all travelers to quarantine for 14 days) and public health guidelines (e.g., social distancing) and the necessity for the public to follow the requirements should be clearly conveyed to the public.

All solution providers, particularly technology companies, should be transparent about the solution's data practices. Some participants disliked the idea of technology companies being solution providers because of the possibility of their data being used for the companies' own business (Section 4.6.4). Meanwhile, as most information-tracking solutions are a result of collaborations among multiple organizations (e.g., health authorities, technology companies, governments, and possibly research organizations), it is important that trust in *all* participating entities involved in a solution be developed and maintained. Therefore, we suggest that solution providers present clear and precise information regarding the solutions' data practices to the public. For example, people could be informed of which solution provider has access to the information users provide, the purpose of accessing users' information (e.g., verifying whether a person is quarantining), and the retention of storing users' data (e.g., users' data will be deleted after they finish the quarantine).

5.3 Factors Linked to Perceived Benefits

Factors perceived as reducing the solutions' benefits are negatively associated with participants' intentions to adopt. Perceived benefits were identified as a main reason for the public to consider using contact-tracing apps [74, 86, 115, 147]. Adding to previous work, we further discovered several factors associated with perceived benefits (Section 4.3 & 4.4). When believing that these factors significantly offset the benefits, participants expressed reluctance to adopt the solution. These factors provide insight into the design of future solutions.

Recommendation 3: Ensure the solutions' individual benefits are provided. Ensuring that the individual benefits of the solution are actually provided will ease people's concerns and attract new users. All participants expressed a determination to be good citizens by complying with health guidelines and helping contain the virus. Therefore, some participants argued that they should be trusted to conduct their civic duty without being treated as criminals (Section 4.4). Interestingly, participants expressed a lack of trust in other people performing the same behaviors, i.e., being good citizens. Participants showed concerns regarding other people disobeying the rules or being dishonest, (e.g., presenting fake test results to be able to travel [135]) and thereby reducing the benefits for other users. Solution providers can develop methods to motivate people to use the solutions properly and limit the possibility of some users reducing the individual benefits of others. For instance, additional verification features could be added to *EP-svc* to verify travelers' test status or to determine whether they have been vaccinated.

Recommendation 4: Minimize the cost of obtaining the benefits of the solutions. The effort required to use the solution could be minimized to make the solutions more appealing to potential users. Participants noted that having to fill in the same contact information each time they visit a restaurant (or other public place [159]) was unnecessary and repetitive (Section 4.3). This perceived overhead of using *DineIn-sol* reduced its benefits. This shows a need for technological support (e.g., mobile apps) to allow customers to quickly provide their contact information. For instance, by scanning a check-in QR code with their smartphones, customers could quickly provide information previously stored on their phones. Furthermore, more privacy-preserving features could be provided, such as allowing dine-in customers to provide nicknames instead of their real names.

Recommendation 5: Highlight the overlooked societal benefits. Increasing the public's awareness of the solutions' societal benefits has the potential to attract new users. *EP-svc* and *DineIn-sol* were developed to provide societal benefits as well, such as enabling businesses to stay open and limit disease transmission [21, 53, 73]. However, compared to the individual benefits of these solutions, the societal benefits were often overlooked by our participants. As emphasizing the apps' societal benefits could encourage the adoption of contact-tracking apps [83], we suggest that all information-tracking solutions enhance the visibility of the solutions' societal benefits and increase people's awareness of these benefits.

5.4 Importance of Individual Benefits

Lack of individual benefits discouraged participants from adopting contact-tracing apps, which in turn reduced the apps' societal benefits. Contact-tracing apps are designed to identify an exposure when users come into close contact with a C-positive person. Some participants with an accurate mental model of the contact-tracing apps questioned their usefulness. Specifically, they did not believe that the apps could provide any individual benefits, as they were careful to avoid close contact with people who were outside of their "bubble" (Section 4.4). Hence, they preferred not to use the app. As a result, the societal benefits of the apps may be reduced due to the small number of adopters. With fewer users, the apps may fail the contact-tracing mission [44, 44, 64, 160].

5.5 Limitations

There are three main threats to the validity of our methodology: lack of first-hand experience by the participants with the solutions we interviewed them about, risk of the participants misunderstanding solutions after reading our descriptions, and limited generalizability of our findings. Also, because of the nature of interviews, our data is self-reported, which is always subjective [6, 87] and is often subject to other limitations, such as selective memory bias [109, 131] and exaggeration [109].

While interviewing participants who have first-hand experience with the solutions would be ideal, we believe that our use of solution descriptions was an acceptable compromise. Many studies have explored non-user participants' perceptions of a system with the end goal of informing the design of such systems. In those studies, participants were placed in imaginary scenarios, such as living in a smart home [62], using or being surrounded by autonomous vehicles [18, 77], and using a contact-tracing app [74, 83, 115, 147]. Our approach followed suit. Considering the results of our study, we believe that implementing our recommendations could benefit solution providers, other researchers, and the public. We did have some participants who had first-hand experience with some solutions (*DCT-app* and *DineIn-sol*). In these cases, we focused on exploring their perceptions of these solutions and the factors they considered *before* using either solution. We did not observe any qualitative differences in the factors considered by the participants who had experience with the solutions and the participants who did not.

We used extensive testing to mitigate the risk of the participants misunderstanding our descriptions. While designing our study, we put extra effort into increasing the readability of the solutions' descriptions to reduce bias and to avoid overwhelming the participants. For instance, we conducted five pilot tests. Still, the potential for participants misunderstanding the descriptions remained.

The generalizability of our findings is limited by the changes to public health regulations and people's lives as the COVID-19 pandemic evolves. If the same participants had been interviewed 6 to 12 months later, they might have reported different perceptions and attitudes. As such, as with the overwhelming majority of studies related to COVID-19, we offer a snapshot in time. Still, we believe that such snapshots are valuable to both researchers and solution developers, as they collectively expose at different points in time a fast-evolving phenomenon.

Our participants were all recruited in Canada, and while the results of our study might be generalizable to other world regions, they will likely need to be validated and adapted to different cultural and social contexts.

Due to the nature of qualitative research, our study and our data are not amenable to quantification, e.g., what percentage of the population considers one particular factor. Nevertheless, our research lays the groundwork for future quantitative studies that can further refine and validate our findings on representative samples.

Further, with the end goal of informing the future design of information-tracking solutions to better contain the current and future pandemics, we focused on exploring the participants' considerations of the solution, instead of participants' individual differences (e.g., cultural background and pandemic-related conspiracy beliefs [84, 140]) or the solutions (e.g., whether the solutions should be implemented). More studies could be conducted to further investigate whether and how people's individual differences affect their adoption intentions.

6 CONCLUSION

We identified four main categories of factors that influenced the participants' willingness to adopt six information-tracking solutions: individual benefits of the solution, societal benefits of the solution, functionality concerns, and digital

safety concerns. Based on the results, we offer several recommendations. First, we suggest that future information-tracking solutions focus on these four aspects. Second, trust in solution providers should be built and maintained. Finally, solution providers could emphasize the societal benefits of the solutions, such as ensuring that the anticipated benefits are provided, minimizing users' efforts to obtain these benefits, and highlighting the overlooked societal benefits of the solutions.

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