Factors affecting adoption of digital contact tracing during the COVID-19 pandemic: a literature review

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Background and Objective: Digital tools have been extensively used in handling the COVID-19 pandemic, but governments struggle with the low uptake of digital contact tracing (DCT). Since this limits its effectiveness in infectious disease control, this topic is important to epidemiology and public health. The objectives of this review are: (I) to discuss the factors affecting DCT adoption in different communities; (II) to compile suggestions to improve DCT uptake; (III) to discuss implications of DCT utilisation in the pandemic on further digital and mobile health development.

Methods: Papers published in English from January 2020 to January 2022 were identified using Boolean operators on PubMed and the *Journal of Medical Internet Research* (*JMIR*).

Key Content and Findings: Literature review shows consolidated agreement that factors affecting acceptance of DCT applications are: (I) technical factors (privacy protection protocols, application design, user experience); (II) social factors (social norms, media representation and coverage, perception of responsible corporations); (III) political factors (government promotion and education, government image); (IV) health concerns (perceived risk of COVID-19, perceived effects of using DCT); and (V) cultural factors. Additionally, it is agreed that intention to use these applications pre-release does not indicate actual usage. Privacy protection, favourable attitudes of society, trust in private corporations, trust in governments, transparency, open communication approaches, perceived health benefits, and values of collectivism favour DCT uptake. Literature disagrees on the association between health awareness and DCT adoption, but most identify a positive association.

Conclusions: Specific to the COVID-19 pandemic, literature recommends repeating these studies in different communities at different time points because social, cultural and political factors are geo-specific and temporo-specific. Beyond the COVID-19 pandemic, developers of digital and mobile health applications should consider data security and privacy consider, perceived functional efficacy and application usability.

Keywords: Digital contact tracing (DCT); contact tracing; infectious disease; disease surveillance; health-seeking behaviour

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Introduction

In response to the COVID-19 pandemic, health authorities adopted a variety of measures, including city-wide lockdowns, travel restrictions, mandatory quarantine, and the test-trace-isolate approach for new confirmed cases (1). Digital tools were extensively used in the handling of this pandemic, including telemedicine, applications that allow self-reporting of symptoms, and digital contact tracing

(DCT) (2,3).

DCT works by having DCT applications installed on smartphones (4). These applications largely use either Bluetooth to detect signals from nearby devices and identify close contacts of the phone owner, or Global Position System (GPS) to identify people present at the same place and time as a COVID-19 patient and mark them as possible contacts (4). Another subset of these applications use QR code or barcode systems, where people scan codes provided by venues to record their travel history (5-8). From that, close contacts of individuals can be inferred, which can facilitate contact tracing efforts by public health authorities.

The first contact tracing mobile applications were rolled out in the first quartile of 2020 largely in the Asia-pacific and Scandinavian regions (4). Other regions had reservations in using these technologies, and controversies regarding the privacy concerns, ethicality and best methods for implementing DCT hindered its implementation (4). The privacy-preserving protocol launched by Apple and Google, which uses decentralised storage systems and Bluetooth-enabled tracking software (9,10), has alleviated these concerns (11). Governments thus swiftly follow suit (4,11), such that DCT became adopted throughout the world.

However, governments' enthusiasm do not appear to translate to that from individuals, which has significant implications because the effectiveness of DCT is tied closely to the size of the effective user base. With each percent increase in adoption of DCT reducing the number of cases by 0.8% to 2.3% (12), a poor adoption may lead to unsatisfactory effectiveness, which would make investments in DCT controversial. From simulations, at least 56% of the population has to be effective app users to suppress the epidemic (13), which means that more than half of the population has to download and comply with its instructions. Thus, even if suggestions of an opt-out policy for DCT applications are adopted, the number of downloads may not be meaningful if phone holders are not using the apps.

Despite moving onwards from the COVID-19 pandemic, DCT remains relevant because it can minimise the risk of new variants causing uncontrollable outbreaks (14), with some speculating that it could strike a balance between infection control and daily activities, thus become the key to returning to normal life (15,16). Moreover, our experience in the pandemic can guide the use of DCT for future outbreaks involving other pathogens (14). Thus, to improve the adoption of DCT, we ought to look into the concerns of the public and factors influencing the adoption of DCT, such that effective strategies can be devised to improve the uptake of DCT. This review explores the factors affecting adoption of applications in hopes to better advise on handling the privacy concerns, reservations on effectiveness, technical inabilities, and poor image. We present the following article in accordance with the Narrative Review reporting checklist (available at https://jphe.amegroups.com/article/view/10.21037/jphe-22-11/rc).

Methods

Papers were identified using Boolean operators on PubMed and the *Journal of Medical Internet Research* (*JMIR*). Peer-reviewed opinionated editorials, original research articles, and review articles with free-access English full-text published between January 2020 and January 2022 have been included in the analysis (*Table 1*), with the last date of search being 2nd February, 2022. The process of identifying and screening articles has been described using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (17) in *Figure 1*. After consideration of inclusion and exclusion criteria, 58 articles remained. The detailed search strategy can be found at *Table 2*.

The *JMIR* has been searched in particular because our initial literature search in the PubMed database revealed that almost half of these articles were published in the *JMIR* (38/80), yet only 3 of their publications are indexed in PubMed. Exploring the articles published by this Journal but in other publications would improve the coverage of our literature search. Six and three of the articles were published by *PLoS One* and the *British Medical Journal* respectively, but they were not searched because their publications have been indexed in PubMed.

Results of literature search

A total of 58 articles have been identified. These articles comprised 34 questionnaire studies, 4 interview studies, 4 reviews, 6 observational studies, 1 experimental study, 4 opinionated article, and 5 mixed methods studies (*Table 3*). The factors affecting the uptake of DCT and suggestions from literature to increase its uptake are summarised in *Figures 2,3* respectively.

Table 1 Search strategy

Items	Specification
Date of search	First date of search: 29 July, 2021; last date of update: 2 February, 2022
Databases and other sources searched	PubMed, *JMIR*
Search terms used	"App", "Application", "Contact tracing", "COVID-19", "SARS-CoV-2", "Perceptions", "Opinions", "Attitudes", "Adoption"
Timeframe	January 2020–January 2022
Inclusion and exclusion criteria	Inclusion criteria
	Article published in English language, or with English translation for the full text
	Access to full text
	Exclusion criteria
	Unsuitable study objectives, including but not limited to usability testing, proposals of prototypes for DCT application, evaluation of cost-effectiveness and efficacy of DCT
	Investigation of digital health tools not used for DCT, including but not limited to applications for symptom tracking and reporting, telemedicine and distant monitoring of chronic diseases, and research-oriented applications
	Lack of description of factors affecting adoption and perception of DCT, including but not limited to general commentaries of public health policies, general commentaries of the use of digital health tools during the COVID-19 pandemic

JMIR, *Journal of Medical Internet Research*; DCT, digital contact tracing.

Factors affecting DCT uptake

Technical factors

Application design and technology used

A major concern regarding DCT applications is about the technology used to identify and record close contacts. Contact tracing technology largely use of low-energy Bluetooth, geo-location tracking, or self-reporting of contact and exposure by barcode or QR code log-in systems (4-8). While a large portion of such software utilise protocols for privacy, such as the Apple/Google protocol, DP3T protocol, OpenTrace protocol, PEPP-PT protocol, ReCoVer protocol, TCN protocol, some do not adopt any protocol (4). Applications of different designs appear to have a difference in acceptance and adoption.

Geo-location tracking conducts contact tracing by recording the previous locations of the mobile device based on GPS technology (4). This has been criticised as collecting additional unnecessary information because the location of contact is irrelevant as long as contacts are identified (32). In a recent questionnaire survey conducted in Ireland, DCT applications based on geo-location tracking was least preferred (53), while a similar study in France has found fear of being geolocated to be a major factor against use of DCT applications (28).

In literature, Bluetooth proximity tracking software has been strongly recommended for its minimal interference to fundamental rights, with strong advocates explaining that this is more desirable than geo-location tracking services (32). Likewise, Bluetooth tracking is most preferred among members of the public because it is considered more privacy conserving than the alternatives (7,53,63).

QR code or barcode scanning technology is another option for contact tracing, where application users are required to scan a QR code or barcode upon entering different premises (4). This is less discussed than geo-location tracking or Bluetooth proximity tracking, but a recent study based on DCT applications in the United Kingdom have found that these terms often carry a negative sentiment arising from its speculated inconvenience because these codes may not be immediately visible, and such applications require manual scanning by application users (66). On the other hand, a questionnaire study in New Zealand, which adopts DCT using QR code technologies, finds social influence important, which is explained by the visibility of use or non-use for QR code-based tracking (21).

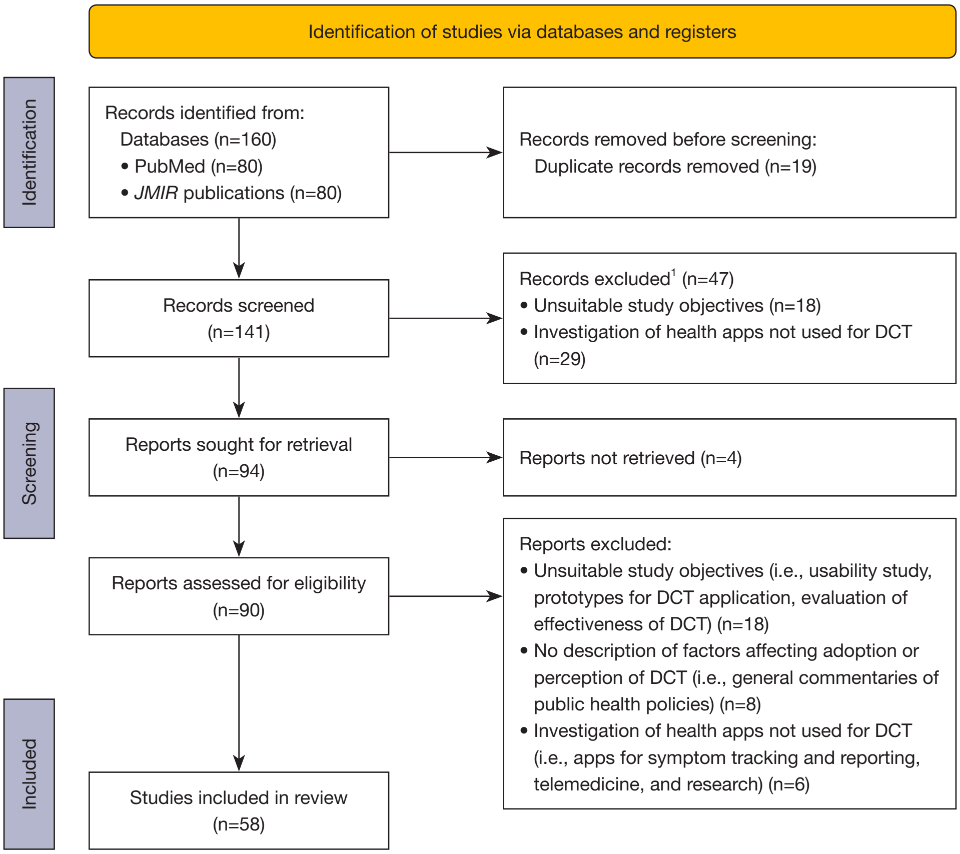

Figure 1 Flow chart indicating inclusion and exclusion of articles. [1], no automation tools were used. All 47 records were excluded by human. *JMIR*, *Journal of Medical Internet Research*; DCT, digital contact tracing.

Table 2 PubMed search strategy

Search number	Search strategy	Results
1	(“app”[All Fields] OR “application”[All Fields])	996,099
2	(“contact tracing”[All Fields] OR “contact tracking”[All Fields])	8,104
3	(“digital contact tracing”[All Fields] OR “digital proximity tracing”[All Fields] OR “digital proximity tracking”[All Fields] OR “digital contact tracking”[All Fields])	150
4	(“COVID-19”[All Fields] OR “SARS-CoV-2”[All Fields])	245,282
5	(“perceptions”[All Fields] OR “opinions”[All Fields] OR “attitudes”[All Fields] OR “adoption”[All Fields])	423,144
6	#2 OR #3	8,106
7	#1 AND #4 AND #5 AND #6	80

Telecommunication based contact tracing refers to the use of phone data supplied by telecommunication companies for contact tracing (34,59). While this option was only investigated by one research group in two studies based in Australia (34) and Taiwan (59), it was interestingly found to be most accepted in both populations.

Centralised and decentralised storage systems

Data collected could be stored either in centralised or decentralised storage methods. The former refers to

Table 3 Summary of published articles

Research method[1]	Study area	Time of study	Technology inquired	Reference
App review	Australia, Georgia, Italy, New Zealand, Norway, Pakistan, Singapore, South Korea, Switzerland, United States	Jun 2020	Bluetooth, GPS, QR code	Elkhodr M (18)
	Switzerland	Jun 2020–Oct 2020	Bluetooth	Daniore P (19)
Experimental study	Canada	Aug 2020–Sep 2020	NA	Benham JL (20)
Interview study	New Zealand	Oct 2020–Nov 2020	QR code	Tretiakov A (21)
	United Kingdom	Apr 2020	NA	Samuel G (22)
	United Kingdom	May 2020	NA	Williams SN (23)
	United States	Spring and summer of 2020	Bluetooth, GPS	Seberger JS (24)
Literature review	Singapore, Ireland, China, South Korea, Norway, United States	Jul 2020–Mar 2021	Bluetooth and GPS	Hogan K (25)
Mixed methods study				
Questionnaire survey	United States	Jun 2020–Jul 2020	Bluetooth	Shelby T (26)
Free-text responses				
Interview study	Austria, Germany, Switzerland	Apr 2020–May 2020	NA	Zimmermann BM (27)
Analysis of media reports		Mar 2020–May 2020		
Literature review	France	Sep 2020–Oct 2020	Bluetooth	Montagni I (28)
Questionnaire survey				
Literature review	United States	Jul 2020–Aug 2020	NA	Hong SJ (29)
Questionnaire survey				
Questionnaire survey	Netherlands	Apr 2020	NA	Jonker M (30)
Experimental study				
Opinionated article	France	NA	Bluetooth, GPS, QR code	Rowe F (31)
	Japan	2020	Bluetooth	Nakamoto I (7)
	NA	NA	Bluetooth	Abeler J (32)
	NA		Bluetooth	White L (33)
Questionnaire survey	Australia	Apr 2020–Jun 2020	Bluetooth, GPS, telecommunication network tracking	Garrett PM (34)
	Australia	May 2020	NA	Thomas R (35)
	Australia	Jun 2020–Jul 2020	Bluetooth	Lockey S (36)
	Belgium	Oct 2020–Nov 2020	Bluetooth	Walrave M (37)
	Belgium	Apr 2020	Bluetooth, GPS	Walrave M (14)
	Canada	Aug 2020	NA	Lang R (38)
	England	Nov 2020; Mar 2021	Bluetooth	Horvath L (39)

Table 3 (*continued*)

Table 3 (*continued*)

Research method[1]	Study area	Time of study	Technology inquired	Reference
	France	Nov 2020	Bluetooth	Guillon M (40)
	France	Apr 2020–May 2020	Bluetooth	Guillon M (41)
	France, Germany, Italy, United Kingdom, United States	Mar 2020–Apr 2020	NA	Altmann S (42)
	Germany	May 2020; Jun 2020; Nov 2020	Bluetooth	Scholl A (43)
	Germany	Apr 2020–May2020	NA	Kaspar K (44)
	Germany	Jun 2020; Jul 2020	Bluetooth	Oldeweme A (45)
	Germany	Mar 2020; Apr 2020; Aug 2020–Sep 2020; Nov 2020	Bluetooth	Kozyreva A (46)
	Germany	Jun 2020	Bluetooth	Blom AG (47)
	Germany	May 2020–Jun 2020	NA	Tomczyk S (48)
	Germany	Mar 2020–Jul 2020	Bluetooth	Walrave M (49)
	Germany, Italy, Netherlands, Spain	Oct 2020–Dec 2020	NA	Witteveen D (50)
	Germany, Switzerland	Apr 2020–Jun 2020; Jul 2020–Sep 2020	Bluetooth	Große Deters F (51)
	Iran	Sep 2020–Oct 2020	NA	Rahimi R (52)
	Ireland	May 2020	Bluetooth, GPS	O’Callaghan ME (53)
	Italy	May 2020–Jun 2020	NA	Caserotti M (54)
	Japan	Dec 2020	Bluetooth	Shoji M (55)
	Netherlands	Apr 2020	NA	Jansen-Kosterink S (56)
	New Zealand	Jul 2020–Sep 2020	QR Code	Gasteiger N (57)
	Singapore	Jan 2021–Feb 2021	Bluetooth	Lee JK (58)
	Switzerland	Sep 2020–Oct 2020	Bluetooth	von Wyl V (11)
	Taiwan	Apr 2020	Bluetooth, GPS and telecommunication network tracking	Garrett PM (59)
	United Kingdom	Dec 2020	Bluetooth	Dowthwaite L (60)
	United Kingdom	Dec 2020–Jan 2021	Bluetooth, QR code	Panchal M (61)
	United States	Apr 2020–Jun 2020	NA	Camacho-Rivera M (62)
	United States	Jun 2020	Bluetooth, GPS	Zhang B (63)
	United States	Jun 2020	NA	Maytin L (64)
	United States	May 2020	NA	Hassandoust F (65)

Table 3 (*continued*)

Table 3 (*continued*)

Research method[1]	Study area	Time of study	Technology inquired	Reference
Observational study				
Analysis of app reviews	United Kingdom	Dec 2020	Bluetooth	Garousi V (66)
Analysis of media reports	Austria, Germany, Switzerland	Jan 2020–May 2020	NA	Amann J (16)
Analysis of mobile app usage	South Korea	Jan 2020; Aug 2020	GPS	Kim H (67)
Analysis of social media	Australia, Canada, Ireland, New Zealand, United Kingdom, United States	Jan 2020–Apr 2020	NA	Doogan C (68)
	Israel	Mar 2020–Apr 2020	NA	Keshet Y (69)
	United Kingdom	Mar 2020–Oct 2020	NA	Cresswell K (70)
Systematic review	Austria, Belgium, Croatia, Czech Republic, England/Wales, Estonia, Finland, France, Germany, Iceland, Ireland, Italy, Latvia, Malta, Netherlands, Poland, Portugal, Scotland, Slovenia, Spain, Switzerland	Nov 2020	NA	Kahnbach L (71)

[1], the research method is defined by the description in the methodology section of the respective studies. If there is no methodology section, or if the research method is not stated, the research method is defined by the categorization of the respective journals. GPS, Global Position System.

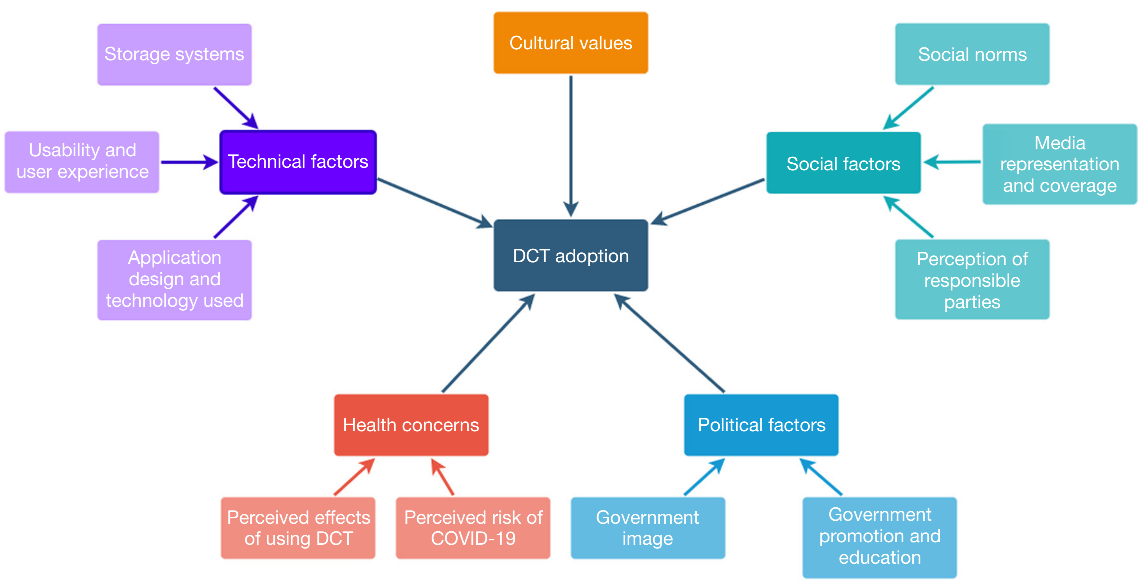

Figure 2 Summary of factors affecting the uptake of DCT. DCT, digital contact tracing.

storage in a central server; the latter, in individual mobile devices (11). It preliminarily appears that there is a general favour for a decentralised storage (63,70) because they are believed to provide better data security and be more in line with data protection laws than centralised systems (70). However, this may be a misconception because

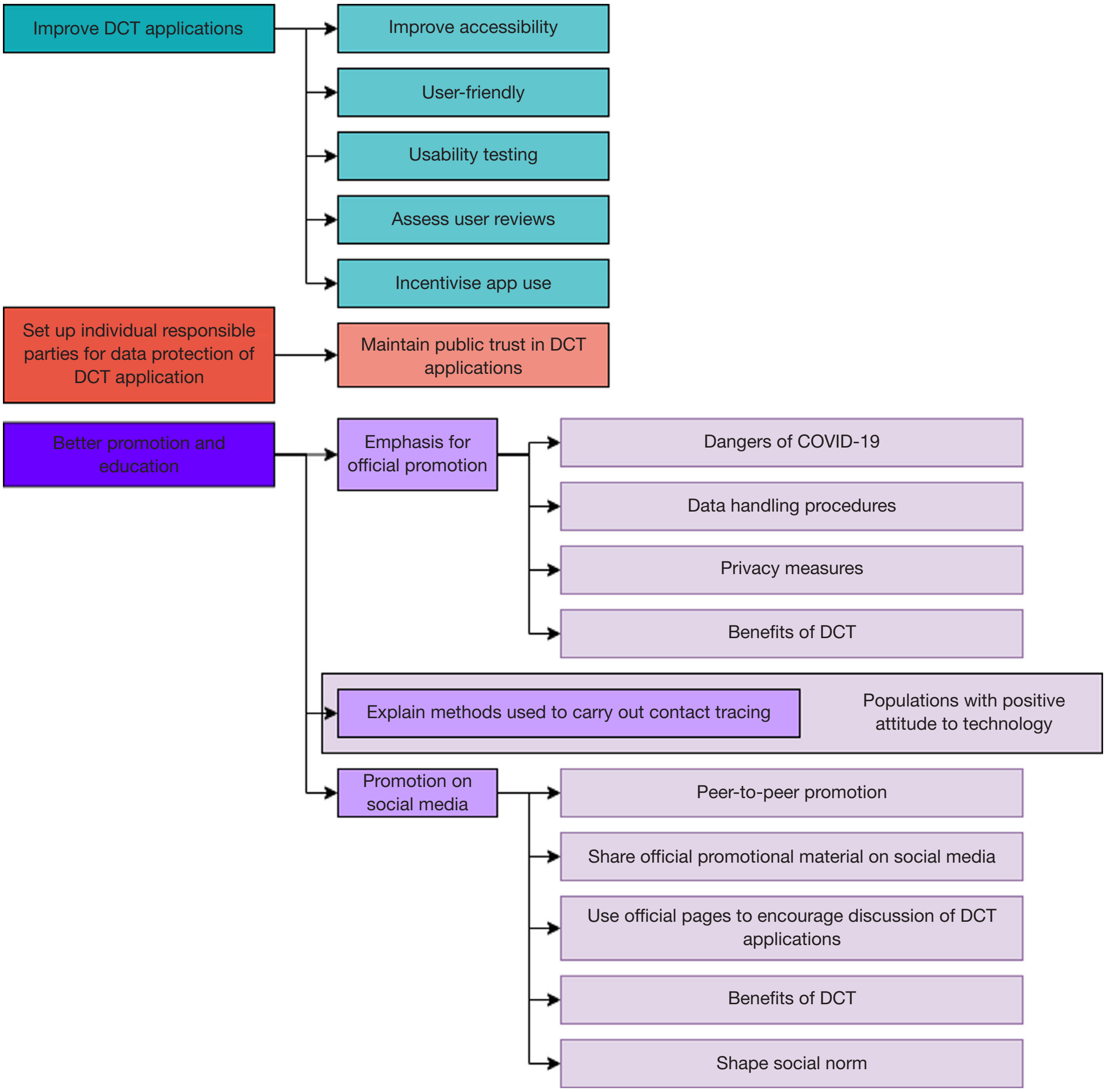

Figure 3 Summary from suggestions from literature. DCT, digital contact tracing.

decentralised systems still have to broadcast travel history to initiate notifications of community contacts (33). The general public may also be ignorant of the additional public health benefits of centralised storage systems, such as allowing more efficient contact tracing and facilitating analysis on large data sets (33). Overall, this reflects a need for public education on the mechanics of DCT applications, and the strengths, weaknesses, and limitations of different contact tracing modalities.

Usability and user experience

DCT requires a sufficiently high effective user uptake to benefit public health. Many studies have revealed participants being unable to download and adopt DCT applications because they do not have phones (37,38,69), or have phones with incompatible operating systems (11,19,35,37,39,46,57,69). Other deterrent factors include concerns over battery (11,25,28,35) and storage use (26,28,35,57).

Usability is also key to maintaining the user base of DCT applications. Various research studies have revealed that unsatisfactory user experience deters continuous DCT use. Common causes for poor usability include the negative impacts of Bluetooth and GPS on battery life (25,28,34,59), region-specific restrictions (66), disturbance of notification system (66), application errors (66), software incompatibility (19,35,38,39,46,57,66,69), and excessive use of data (35) and storage space (28,35,57). While user experience is less relevant to the initial intention to download, it is crucial for DCT since it retains current users, which contributes to a sufficiently large user base for functional efficacy (12,13).

Social factors

Social norms

The impacts of social pressure on the uptake of DCT has been a recurring theme in literature. Social norms are reported to influence intention to use and initial trust in such applications, both which directly affect actual use of DCT applications (39,45,58,65). Despite a number of studies showing that people might consider using the app if it is the social norm (16,23,39,58), possibly because people are conditional contributors to social good such that they participate in activities others do (16), the effect of social norms on DCT adoption varies under different the conditions.

First, the importance of peer pressure changes with the proportion of people using DCT, and whether identifying users and non-users are easy. A survey conducted in Australia has found that social influences is a factor for not adopting DCT (35), which differs from that in New Zealand, where peer influences play a secondary role in driving DCT use. A suggested explanation is that DCT in New Zealand is QR code-based, which makes app use highly visible, thus intensifying the effects of peer pressure (21). Findings that New Zealand has a higher proportion of frequent users (55%) than that of Australia (37.3%) further support this argument (35,57). In conclusion, peer pressure might only encourage DCT use communities with an already high adoption of DCT, and where use or non-use is obvious.

Second, the importance of social pressure varies with socio-demographic backgrounds. Shoji *et al.* reports that within the Japanese community, community attachment is a major factor for DCT application adoption among younger age groups, but not for older members, among whom trust in the government and health concerns play larger roles (55). This suggests that even within the same community, members of different age groups have different foci, and that younger people are more readily affected by peer pressure.

Media representation and coverage

Media presentations of different topics influence reader's beliefs. In Austria, Germany, and Switzerland, broad contextualization of DCT applications in mass media can further doubts on the legality, necessity, and adequacy of collecting travel and contact information with technology (27). This can further perpetuate scepticism on digital tools and information collection regardless of the official rationale, scope and function of the DCT apps, thus undermining their reception (27).

Furthermore, topics presented by the media also affect people's perception of DCT. For-profit media and social media platforms disseminate information that their target audience would agree with, reinforcing misconceptions (16,38). Reports of debates within academia leads to scepticism and reduced confidence in the government, and conflicting expert advice reduces public's trust towards them, which can lead to poorer adherence to any suggestions perceived as contentious (16).

Perception of responsible parties

The trust in big tech corporations is a factor affecting DCT adoption and use. This is because they facilitate the design and implementation of DCT by formulating privacy protocols and allowing such applications to be downloadable on their platforms. Research reveals concern around the involvement of Big Tech corporations in public health solutions in the United Kingdom (22,39), Ireland (53), continental Europe (16), Australia (68), New Zealand (68), and the United States (63). Some suggest that such distrust originates from speculations that personal data would be used for financial gains, which arise from known scandals of Big Tech corporations, such as that of Google Deepmind (22). The perception that private companies do not respect privacy is arguably a common misconception because they have played pivotal roles in protecting privacy, for example in developing the Apple/Google protocol which standardises protection of privacy (24). Nonetheless, their poor perception can cause hesitations in using DCT, thus remains an important factor to consider upon enforcement.

Furthermore, trust in other leaders of DCT also influences its uptake. Distrust in app developers appears to hinder adoption of DCT (46,60), while involving trusted parties in DCT efforts make it more acceptable, even if the risk of surveillance remains (34). For example, some studies have found that the reception of DCT can be improved if

Table 4 Common misconceptions of DCT

Misconception	Reference
Bluetooth carries location information	(63)
DCT is used for population surveillance	(16,20,22,23,25,27,40,42,53)
Identifiable information is collected	(23,24,61,63)
Data will be made available to public	(23)
Data will be made available to third parties	(23,24,39)
Data will be made available to technological corporations	(24)
Travel histories will be made available to foreign governments	(16,27)
The app tells the user if someone around them has COVID	(23,35)
The app tells the user if it is safe to go out	(35)
The app is monitored by humans	(60)

DCT, digital contact tracing.

trusted health authorities independent of the government are involved in data handling (39,64).

Political factors

Government promotion and education

First and foremost, governments should take the initiative to educate citizens about the importance of DCT and the functions of DCT applications. Government promotion and education is a key factor motivating app downloads (49), and up to 56% of people are reported to download DCT applications due to promotion by government officials (34). Regardless of the enthusiasm of governments in taking up DCT as a public health measure, study participants often directly expressed that they feel a lack of promotion, and that they are not well-informed about the topic (20,23,27). Other studies found that many are confused about the role, function, and scope of DCT applications (23,28,38,63). Among the many misunderstandings, the misconception that DCT is used for population surveillance dominates (16,20,22,23,25,27,40,42,53). Other misconceptions are summarised in *Table 4*.

Government image (trust and confidence in government)

Given that up to 70% of DCT applications are government-backed (4), the relationship between government trust and acceptability of such applications were investigated by many. Distrust in the government was a key factor leading to poor adoption of DCT (34,35). On the other hand, trust in governments was found to be a key factor for acceptance of such applications in many questionnaire studies (11,21,22, 28,29,36,39,40,42,45), with participants of interview studies indicating that trust in and transparency of local and national authorities are prerequisites for DCT uptake (21,27). When focusing on different age groups, Shoji *et al.* demonstrated that trust in the government is a key factor of consideration for middle-aged people (40–59 years old) (55).

Confidence in the government in handling the pandemic has been found to be associated with adoption of DCT. Witteveen *et al.* found that those who became unemployed because of the pandemic have a decreased adoption of DCT—their uncooperativeness explained by a reduced confidence in the government in handling the pandemic (50). However, Oldeweme *et al.* suggests that short term measures can promote trust in the app, even for those who were initially critical of the government (45). This factor has greater practical significance than long-term trust in the government because it is immediately modifiable (22).

Adopting an open and negotiable approach enhances transparency, which can improve the government's image. A study based in France found that a coercive approach is associated with increased skepticism of DCT effectiveness and questions about its adequacy (31). Despite the calls for an opt-out approach of having DCT applications be installed by default to reduce efforts required by people and the impacts of procrastination, preliminary evidence suggests that they are less supported than opt-in schemes (25,42). Other studies found that participants valued the option to not use the app (46), echoing the finding that choice is an important motivator for DCT adoption. This is key in mobile health issues because app downloads do not directly translate to frequent and effective application use. Proactive approaches, where the government addresses ethical, legal and social issues raised regarding DCT (27), have been recommended by various researchers (27,35,45). To achieve this, authorities should identify channels of communication to facilitate discussion between stakeholders, including governmental bodies, citizens, app developers, and academics in related fields before when implementing DCT (11,42,45).

Being transparent by making scientific evidence publicly available can also improve the government image. Scientific rigorousness of usability testing and application function is a main theme in mass media (16). The lack of transparency was particularly criticised in the Austrian media (27), whereas epidemiologists and app developers regularly discuss app designs and DCT in local newspapers in Switzerland and Germany, enhancing transparency in the development of DCT applications (27). These might be factors related with the differences in adoption rate of DCT apps, which is higher in Germany (29.15%) and Switzerland (33.18%) than in Austria (14.81%) (71). Another method to be make scientific evidence openly accessible is to make the source code of DCT applications publicly available (16,68).

While improving government image is difficult, doing so goes a long way. Through literature review, New Zealand appears to be the only Westernised democracy where DCT is unanimously positively received, which was attributed to its high government trust and confidence (35,57). With a positive image of the government, there is significantly less concern about abuse of data and government surveillance, such that participants of interview studies even express willingness to give up privacy for functional efficacy (35).

Health concerns

Perceived risk of COVID-19

The perceived risks of COVID-19 to oneself, to one's family and friends, and to one's community affect uptake of DCT applications. It has been found that harbouring concern for one's own health and the belief that using DCT can reduce their infection risk promotes adoption of DCT (11,28,34,38, 41,46,51,54,57,59,63,65,69). This might be relevant to one's predisposing factors to COVID-19 disease, such as age (55) and underlying comorbidities (62). A study based in Japan has found that protecting one's health is an incentive to use DCT, especially for those aged 60 and above, suggesting that they are particularly concerned about the risk of COVID-19 because age is a well-known risk factor for severe disease (55). Likewise, a poor general health status appears to motivate DCT adoption (28,30,47,50). When focusing on patients with chronic health conditions, those with pre-existing health conditions appear to be more supportive of DCT (63), especially patients with obesity and chronic respiratory diseases (62). However, the same study finds patients with a history of mental health conditions being more likely to adopt DCT (62), which might be because they are more wary of COVID-19, thus creating a higher perceived health risk (62). However, it must be acknowledged that concern over one's health and poorer health status has been found irrelevant to DCT adoption in some studies (37,53).

The perceived risk of COVID-19 to people around oneself is another factor affecting DCT uptake. The will to protect family and friends is often found associated with DCT adoption (21,27,28,42,57,60), especially for older adults, which might be because elderly are more altruistic and considerate (60). The sense of connection and responsibility to one's community (28,42,43,55,57,58) and concern for the health of members of broader society (27,57,59,60,65) has also been found to promote DCT adoption.

Perceived effects of using DCT

For many, both the advantages and disadvantages of DCT on health are evaluated. In terms of physical health, the perception that DCT benefits the health of oneself and one's community by preventing disease motivates DCT adoption (23,28,30,40,43,49,60) and vice versa (11,19,25,28,35,37,39,46,53). This is echoed by findings from media analysis, which reflects that the effectiveness of DCT was a major topic of discussion in media (11,16,70). This includes discussions on the importance of having sufficient application users for meaningful effectiveness (16), and the cost-effectiveness of DCT compared to core infection control measures (11,70).

While the benefits of DCT to physical health are well-agreed upon, the impacts on mental wellbeing are more obscure. Continuous feedback that one's contacts have been found positive for COVID-19 could lead to anxiety and stress when using DCT applications, deterring potential app users (37,42,56). However, some might be more optimistic and enjoy the clarification of whether or not one has been in contact with COVID-19 carriers (21). It was also foreseen that DCT could improve the illness experience by automising and anonymising contact tracing efforts, such that patients need not worry about telling acquaintances that they have been infected with COVID-19 (21).

Differing cultural values between Eastern and Western communities

Research on this topic is largely Western-centric and based on single countries, thus direct comparison across countries may be unfair. However, the divide between the East and the West is evident. The difference in cultural values and priorities between the East and the West, where Westernised communities value individual rights and freedoms as opposed to collectivist values in the East, has been pointed out in interview studies (23). The success of DCT in Asian countries, such as China, Singapore, and South Korea, is acknowledged by interview participants (27), and the lack of similar examples in the West is often explained by the incompatibility between democratic values and DCT, which can be abused for population surveillance, reminding people of totalitarian states (23,27). Similar comparisons are seen in media reports, showing how cultural values is a common topic of discussion (16).

Our literature search can add to this discussion. From *Table 3*, most publications are based on Western countries, reflecting that there is more academic discussion about and interest in the adequacy, acceptability, and adoption of DCT in the West. A possible explanation is that DCT is more controversial in communities with Western influences, which inspires academic interest and stimulates research efforts in this regard.

Suggested methods to improve DCT uptake

Improve DCT applications

Improving the accessibility of DCT applications is integral to increasing the initial uptake of the application and maintaining a sufficiently large effective user base. This includes ensuring that DCT is available for those who want to participate, and that it is practical and easy enough to practice. First and foremost, if DCT is carried out by having out by applications installed on mobile phones, a high local mobile phone penetration rate is prerequisite for effective DCT (18). Communities that greatly desire to implement DCT but struggle with incomplete mobile phone penetration should consider alternatives for those without smartphones, such as tag-based DCT systems (26).

The design of DCT applications affects how user-friendly the application is, and improving it can benefit user experience and usability of the application. Usability testing is a main method to collect feedback about the DCT application, and is recommended to be done before the initial rollout (25,37,57). Some concerns can only be made known after long-term use by the public, such as issues with battery drain and location restrictions, thus post-market surveillance has also been suggested (57). User reviews can suggest new in-app functions (46), such as venue checkout for QR code and barcode based apps (61); change of district, state, or country (61); and customization (71). Additionally, app users show interest in the details of their contact with a COVID-19 patient, hence app developers could consider providing more information about the time, location, and duration of contact (51,61). Some have suggested providing in-app information about privacy protection measures and the mechanics of contact tracing (20,61). In response to complaints about the notification system, app developers could consider improving it or allowing customisation (61). To further improve the user experience, the user interface could be optimised (61), and the application could be made more engaging and interactive (71). An interesting suggestion is to incentivise app use (20,37,71), such as by gamification (20) and providing rewards for continuous use like discounts (38).

One way to integrate these suggestions might be to use chatbots to allow people to find out about the application, COVID-19 and their contact history. This could enhance user engagement, while providing people the opportunity to learn about how the app functions and the details of their contact history. This allows people to customise their user experience, while preventing the interface from being overly cluttered.

Setting up independent responsible parties for data protection of DCT applications

Maintaining public trust in the DCT application is key to alleviating prevailing worries regarding data security, privacy, and functional efficacy. Prior to enforcing DCT, governments should assess their local condition to evaluate if DCT is possible, which includes factors such as the trust in the government (45) and the attitudes to technology, privacy and public health, because these factors are affected both by political and cultural factors (25). Many have suggested cooperating with other stakeholders in managing DCT applications, such as by involving trusted healthcare providers (64) and having expert supervision (69). Some suggested having government-independent groups comprising epidemiologists, app developers, representatives from the government and healthcare providers be responsible for the DCT applications, in hopes that the app is trusted even if either party is not (11,16,42,69). However, it must be acknowledged that it may be inefficient at times, such as when the government is already trusted (21). Governments are suggested to maintain effective communication with the public throughout the implementation of DCT (29,45) to dispel misinformation (28,40) and demonstrate that the government is open to communication and negotiable to improve its image (16).

Better promotion and education

Despite the wide use of DCT applications, research reflected the need for better promotion and education. Study participants often reflect that they do not feel well-informed or educated about DCT (14,23,27). The many prevailing misconceptions about DCT (*Table 4*) and factors found to influence the adoption of these apps, can be used to guide public education (28). To appeal to people and prevent them from fixating on common factors of concern, emphasis can be placed on the dangers of COVID-19 (52,56,59), and the data handling procedures (28,46,59,67,69), privacy measures (28,38,46,59), benefits (28,29,34,52,64,67), and simplicity (28) of DCT. Depending on the people's attitude to technology, governments could also provide more details of how they carry out DCT (38,46).

Since peer pressure and social norms motivate app use, many suggest utilising social media for peer-to-peer promotion (34,37,51,58). Testimonials from DCT application users can be uploaded to social media (37), and government pages could be used to encourage discussion of DCT applications (51). The government can also encourage peer-to-peer promotion by allowing people to share the application more easily (34,51,58). Such social media coverage may help shape the social norm (57). Having target groups for promotion in each campaign might maximise cost-effectiveness, and some suggestions for target groups include those most vulnerable to COVID-19 (37) because they are most at risk of COVID-19, and young adults (64) because they have highest mobility but are least receptive to using DCT.

Implications for mobile and digital health initiatives

The emergence of the Omicron variant may mark the final pages of the COVID-19 as a pandemic. However, our experiences in implementing DCT in the pandemic remains valuable because it is an example of large-scale implementation of digital health and mobile health initiatives. Thus, a retrospective review of the challenges in applying DCT in the pandemic can serve as a case study to identify challenges faced with mobile and digital health, and how health-related mobile applications should be handled for years to come.

Existing research gaps

While the adoption of DCT is a well-researched topic in certain geographical locations, there has been little cross-country studies. Since DCT adoption changes with social and cultural contexts, pandemic severity, and other public health measures, research studies should be repeated across the duration of the pandemic, taking new health policies, such as vaccination programmes and reopening of borders into consideration. Cross-country studies could allow for better comparison between different conditions, which would better advise public health officials. Common concerns identified to be hindering adoption could be remedied by collective efforts of international governmental bodies or groups. For example, since the distrust in big tech corporations appears to be a recurring theme across various countries and sociodemographic groups, it may be more efficient to have multinational technological corporations handle these issues than individual governments. Mixed methods studies using different research methods to supplement each other (27) can be adopted for future research.

Furthermore, research regarding this topic suffers from recurring limitations. Interview studies are strong at revealing qualitative information that are not anticipated, of which misconceptions and misunderstandings of how DCT applications function and technological errors encountered in using DCT applications are particularly important. However, most interview studies prime participants before conducting the interview by briefing them about how DCT is carried out, its functions, and its limitations. Thus, they fail to completely represent real-world conditions where the population largely hear about DCT from media reports and health officials instead of scientists specialising in public health, mobile health or digital health. Regarding questionnaire studies, their strength lies in cross-sectional investigation of large populations. However, since questionnaire surveys require self-reporting, such studies suffer from reporting biases, recall biases, and misclassification biases (62). In particular, for both questionnaire and interview studies, a common limitation includes the online recruitment of study participants (23,24,26-28,42,48,57,58,60,61,64), or online data collection (14,23,24,28,37,38,42,47,48,56-58,60,61,64,65), which makes internet access a pre-requisite for participation. While this is may be appropriate for target groups with high internet access, such as university students (28,64), this leads to a selection bias towards population groups with high digital literacy or those with stronger opinions on the issue, and an under-representation of those who are apathetic or do not have internet access and mobile devices. Media analysis serves purposes in identifying the main themes of the discussion, and is one of the easier methods to obtain a panoramic view of the discourse regarding DCT over time. However, resolution of doing so may be low, since only major sentiments and topics of discussion would be captured.

Handling collaborations with big tech corporations

Big tech corporations have had a pivotal role in handling the COVID-19 pandemic. From early in the rise of DCT applications, Apple and Google were involved in setting up the Apple/Google protocol for DCT applications (9,10), which was important for outlining the ethical guidelines. While some argue that this protocol is more privacy conserving and should be preferred over having no protocol at all (4), people remain wary of the involvement of private companies in DCT, especially because travel histories, contact histories, and health information can be considered sensitive personal data.

Hence, it is important to meticulously manoeuvre the relationship between such big tech corporations and health groups, when collaborating to promote new digital health solutions. A possible solution to this is to set up independent responsible parties to oversee development of mobile health applications, which was similarly suggested in the case of DCT applications to handle the COVID-19 pandemic (11,16,42). It is explained that such groups appear less connected with the core of big tech corporations and allow them to be better trusted by the public, while also improving the perception and transparency of mobile health applications (42).

Importance of usability testing

Since usability and user experience is crucial to maintaining effective use of DCT applications, similar is to be expected of future digital health applications. With DCT applications being developed under urgent conditions, usability testing was probably not done in a stringent enough manner, leading to a poor user experience. Regardless, despite poor usability and user experience being reasons for uninstalling the app for some, other factors can motivate continued use of the application, including the perceived immediate health benefits of protecting the health of oneself, their family and community.

Future digital health applications developed outside of the pandemic situation might experience higher expectations for usability, while also appeal less if they are viewed to solve a less pressing situation than the COVID-19 pandemic. Thus, stringent and thorough usability testing is recommended.

The utilisation of artificial intelligence to analyse textual data can facilitate app development and usability testing. Following the increased utilisation of this research method in recent years, our literature search similarly found research studies using artificial intelligence for textual analysis. Cresswell *et al.* used deep learning models to analyse sentiments of posts on social media platforms regarding applications in the United Kingdom (70), whereas Doogan *et al.* enquired the sentiments of different non-pharmaceutical interventions, including DCT applications, across six countries (68). Garousi *et al.* analysed app reviews on application distribution platforms using data mining, sentiment analysis, and topic modelling approaches (66). Such methods could be used similarly to understand user experiences and impressions of future mobile health applications.

Strengths and limitations

To the best of our knowledge, we have presented the first literature review on this topic.

This is crucial to improving DCT applications, which may be critical in the COVID-19 pandemic because it can strike a balance between infection control and the resumption of normal lives. It can also inspire further developments of mobile and digital health because DCT applications present a great opportunity for investigating the reception of mobile health applications in the general public, instead of specific patient groups. Another strength is that we have identified factors that affect perception and behaviour respectively, which could be challenging when focusing on individual studies because a majority of them are cross-sectional projects conducted either before or after DCT applications were made available, thus evaluates evaluating either perception and adoption. Our literature review also provides preliminary information on the temporal changes in factors motivating DCT uptake, which there is limited research on because longitudinal studies are scarce. Lastly, our broader perspective allows us to look at research from different places and compare different communities, which could provide directions for further research and insights for global health coordination.

However, it must be acknowledged that our literature review excludes articles published in other languages without English translations. This could explain the bias towards certain countries, such as the United States, the United Kingdom and Germany, and such selection biases should be considered when understanding our conclusions drawn from comparisons across regions. Additionally, this work is also limited by the limitations of the studies reviewed. This includes selection biases arising from online recruitment and distribution of study participants. Since this is a contemporary issue, there are little standardised frameworks for research on this topic, which also limits the comparisons across studies. Thus, we have reservations on our understandings, and they should be taken with consideration of these factors.

Lastly, our literature search is not exhaustive because we have only included articles indexed by PubMed or published in the *JMIR* publications. While many articles identified in the PubMed search has been published in *JMIR* (38/80), only three of their publications are indexed in PubMed, hence conducting a search in the *JMIR* publications improves the coverage of our literature search. However, articles published in other journals not indexed by PubMed remains unidentified. We recommend conducting more thorough reviews that include such articles, which can be achieved by searching non-healthcare related databases and grey literature.

Conclusions

Our literature review identified a variety of articles, which are largely Western-centric and comprise of questionnaire surveys, interview studies and media analysis. The uptake and adoption of DCT applications are affected by technical, social, governmental, and cultural factors, as well as health concerns. Technical factors include the data security and privacy concerns, as well as usability and user experience. Social factors refer to social norms, media representation and trust in organisations involved in DCT, while governmental factors concern the strength of government-led promotion and the confidence in the government. The perceived health hazards of COVID-19 and the perceived utility of DCT in disease control appear to affect uptake, as do cultural values of the community in question. Some suggestions to enhance the reception and adoption of DCT are to reduce technical problems encountered in DCT applications, to set up responsible groups for DCT applications that are independent from existing governmental bodies, and to strengthen promotion and education. In addition to the improving DCT applications for better disease control upon outbreaks of emerging variants of concern, this literature review provides preliminary recommendations for mobile and digital health in general. Collaborations with big tech corporations should be handled delicately, and usability testing should be more stringent and rigorous. After launching the app, analysis of app reviews and social media posts are efficient methods that could be considered when evaluating user experience.

Existing research gaps, including the lack of longitudinal research and investigation in non-Western communities, should be addressed to facilitate public health policy formulation in outbreaks of currently-circulating SARS-CoV-2 variants and beyond.

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