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Mobile Applications Leveraged in the COVID-19 Pandemic in East and South-East Asia: A Review and Content Analysis

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BL conceived the study and acquired support from CoronaNet Research Project. SAI and BL developed the study protocol and designed the data extraction rubric. Two authors independently reviewed the mobile applications, extracted, analysed and interpreted the data (BL and TZ for app features, BL and SAI for app functions). BL and SAI wrote the manuscript. The authors are grateful for the generous support of Dr Cindy Cheng at CoronaNet Research Project, whose expert guidance assisted in strengthening the manuscript

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The CoronaNet Researchers Working Paper Series

The CoronaNet Working Paper Series encourages CoronaNet researchers, who are mostly students volunteering their time, to go beyond the crucial work of gathering and coding information about COVID-19-related policies and hone their research and writing skills by conducting their own analyses inspired by the CoronaNet data. The working papers are the capstone of a program which offers research assistants the opportunity to explore research topics of genuine interest to them, acquire and practice the requisite skills to analyze the CoronaNet data, learn more about the dataset to which they have contributed, practice their academic writing skills, and collaborate with their peers in research and writing. To this end, the program entails seminars on research methods and academic writing, detailed introductions on the publicly released CoronaNet data structure, and tutorials on conducting quantitative analyses of the data. In addition, CoronaNet principal investigators provide oversight and feedback on paper drafts while Working Paper Series coordinators organize the program series. The papers in this series are thus *not peer-reviewed* but provide an opportunity to learn about preliminary findings that arise out of the CoronaNet database.

CoronaNet Research Project

The CoronaNet Research Project (https://www.coronanet-project.org/) gathers, systematically codes, and makes publicly available information about government policies put in place in response to COVID-19. It is led by researchers at the Chair for International Relations at the Hochschule für Politik at TUM and TUM School of Management, NYU Abu Dhabi, University of Southern California, Nazarbayev University, Universidade Brasilia, the Hertie School and the Fors Marsh Group. The project relies on the help of experienced staff researchers who serve as regional and country coordinators, and is made possible by more than 500 volunteer researchers from around the world.

Abstract

The COVID-19 pandemic led to increased attention to digital tools to support governmental public health policies in East and South-East Asia. Mobile applications (or apps) related to COVID-19 continue to emerge and evolve with a wide variety of characteristics and functions. However, there is a paucity of studies evaluating such apps, with most of the available studies conducted in the early days of the pandemic. This study aimed to examine free apps developed or supported by governments in the East and South-East Asian regions and highlight their key characteristics and functions. Also, we aimed to interpret how other COVID-19 policies were associated with the introduction of these apps. We systematically searched for apps in the Apple App Store and the Google Play Store and analysed the contents of eligible apps. We included the mobile apps released or updated between 1 March 2020 and 7 May 2021 in Singapore, Taiwan, South Korea, China, Japan, Thailand, Hong Kong, Vietnam, Malaysia, Indonesia and the Philippines. The CoronaNet Research Project database was also used to examine the timeline of public health policy commencement dates to the release dates of the included apps. Of the 1,943 mobile apps initially identified, 46 were eligible, with almost 70% of the mobile apps being intended for the general public. The most common function was health monitoring, followed by raising public health awareness through education and information dissemination. Significantly, most apps for quarantine monitoring were mandatory for the target users or a population subset. Most mobile apps emerged close to the public health policy commencement dates in the early stages of the pandemic. Mobile apps with functions related to COVID-19 vaccines began to appear parallel to vaccination rollout. In East and South-East Asia, most governments employed mobile health apps as adjuncts to public health measures in this pandemic for tracking COVID-19 cases and delivering credible information.

Keywords: mobile applications; eHealth; mHealth; digital health; telemedicine; telehealth; COVID-19; coronavirus; pandemic

Mobile Applications Leveraged in the COVID-19 Pandemic in East and South-East Asia: A Review and Content Analysis

Introduction

Background

The role of digital technology has reached new heights, with 93% of the world's population having access to mobile broadband networks by 2020 (ITU, 2020). Today, with more than half of the world's population (approximately 3.8 billion) owning a smartphone, there is an enormous potential and still growing opportunity to effectively incorporate mobile apps into pandemic control strategies (Ssali, 2020). Since the World Health Organization (WHO) declared a global pandemic due to the 2019 novel coronavirus disease (COVID-19) in March 2020, the demand for digital tools to reinforce public health measures has increased dramatically worldwide (WHO, 2020). Hence, many governments around the globe have developed mobile apps to help flatten the curve of the growing number of COVID-19 cases (Alanzi, 2021; Clavier & Ghesquiere, 2021). Before the advent of vaccines, many governments in East and South-East Asia, including Singapore, Taiwan, China, South Korea, Vietnam, and other neighbouring countries, had gained unprecedented attention for their effective COVID-19 containment and incredibly low death tolls compared to countries in the West (Chorzempa & Huang, 2021). These success stories of flattening the curve, however, were not accomplished in a day. Lessons from the harsh experiences with severe acute respiratory syndrome (SARS) in 2003 and the Middle East respiratory syndrome (MERS) in 2015 have led many governments in this region to overhaul their public health systems to better prepare for the next round of outbreaks (An & Tang, 2020; Chua et al., 2021; Lim, 2015; Liu, Xu, Wang, & Wang, 2020). These experiences of epidemics created a culture of mask-wearing, solidarity, and collective responsibility in the general public in these countries (Navarro, 2021). Also, critical medical capacities were augmented while early warning systems and relevant policies were established long before COVID-19 was first identified (An & Tang, 2020; Chua et al., 2021). In addition, they have actively capitalised on technological solutions to contain the pandemic, leveraging existing digital infrastructure such as the ASEAN Smart Cities Network (ASCN) (Clavier & Ghesquiere, 2021; Huang, Sun, & Sui, 2020). Evidence demonstrated that their proactive and robust systematic actions for effective resilience had been supported by digital solutions, assimilated in their public health policies (Clavier & Ghesquiere, 2021; Ho, Caals, & Zhang, 2020; Nageshwaran, Harris, & Guerche-Seblain, 2021; Patel & Sridhar, 2020). With

other online platforms or geographic information systems (GIS), mobile applications have had a pivotal role in these digital solutions (Clavier & Ghesquiere, 2021).

Given diverse economic sizes and digital adaptation in the East and South-East Asian region (The World Bank, 2016), it is crucial to know how these governments have developed readiness and abilities to deploy digital technologies integrated with public health measures (Chorzempa & Huang, 2021). To date, however, there is a paucity of research in this region evaluating the mobile apps developed for the COVID-19 outbreak (Islam, Islam, Munim, & Islam, 2020; Noronha et al., 2020). Although there have been some studies investigating COVID-19 mobile applications, they were conducted in the early days of the pandemic or evaluated mobile applications on a global scale (Alanzi, 2021; Davalbhakta et al., 2020; Elkhodr et al., 2021; Islam et al., 2020; Ming et al., 2020; Noronha et al., 2020; Osmanlliu et al., 2021). Given the rapid progression of the pandemic, there is a need for an up-to-date review of mobile apps focusing on COVID-19-related apps, particularly focusing on this region.

Objectives and Research Questions

The primary objective of this review is to explore mobile apps dedicated to COVID-19 that have been introduced by governments in East and South-East Asia. This was achieved through three distinct questions:

1. What apps related to COVID-19 are currently freely available for users in popular app stores in this region?
2. What are the characteristics and functions of these apps?
3. How do these apps correlate with and support other public health measures to help reduce the spread of COVID-19?

Through these questions, we systematically identified mobile apps in this region that have been developed as a public health response to COVID-19. Concerning this aim, we examined the date of release, developers or owners, available platforms, uptake requirements, target users and underlying technologies of each mobile app. In addition, we provided details of the functions of each app in terms of relevant public health measures. We also visualised graphically to compare the timeline of publication of these apps concerning the introduction of relevant public health policies. This review has relevance in contributing a more recent synthesis of knowledge regarding the mobile apps available for COVID-19 and informing

governments of the various approaches and capacities of mobile app-based interventions for supporting the pandemic efforts.

Materials And Methods

Search Strategy

This study adopted a systematic search strategy to identify the mobile apps using a modified version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines (Tricco et al., 2018). Adjustments were needed because of the different search nature of mobile app stores.

To overcome the time constraints and facilitate the selection of governments in East and South-East Asia to focus on, we referred to Bloomberg's Covid Resilience Ranking evaluating the 53 largest economies on their success at containing the virus (March 2021) (Hong, Chang, & Verley, 2021). This ranking covers a wide range of COVID-19 status and quality of life in the pandemic, from mortality rates and COVID-19 testing to vaccination and lockdown severity (Hong et al., 2021). From this ranking, we selected 11 governments which are in the East and South-East Asian region, and nine of these governments have been deemed amongst the top 20 economies with the most cohesive responses to the pandemic as of March 2021: Singapore, Taiwan, Hong Kong, South Korea, China, Japan, Thailand, Vietnam, and Malaysia. The summarised details of the scores of each selected government based on Bloomberg's Covid-19 Resilience Ranking in March 2021 are presented in Table S1 in Multimedia Appendix.

We chose the two largest app stores worldwide, the iOS-based Apple App Store and Android-based Google Play Store, to search for potentially relevant mobile apps released or updated from 1 March 2020 to 7 May 2021. The following terms were used in this search: "COVID-19", "COVID", "coronavirus", "corona virus", "corona" and "SARS-CoV-2". In order t To circumvent the regional restriction setting for searching apps, we utilised a website, fnd. ios, to look for apps on the Apple App Store and changed the region settings in the Google Play Store (fnd.io, 2021; Google Play, 2021). News articles, media reports results were also searched to find further eligible apps that may have been missed. For searching the literature, MEDLINE and Google Scholars were explored specifically on the COVID-19 response using the terms ("digital health" OR "m-health" OR "mobile health" OR "e-health" OR "mobile apps") AND ("COVID-19" OR "coronavirus" OR "SARS-CoV-2").

To obtain the public health measures introduced by the governments, we utilised the dataset of the CoronaNet Research Project collating governmental policies worldwide (Cheng, Barceló, Hartnett, Kubinec, & Messerschmidt, 2020). This project comprises a dataset providing comprehensive government policies across 195 countries, apprehending 18 broad policy types, including timings of each policy. We selected national-level policies of 11 governments and validated relevant policies by checking data sources. We narrowed 18 policy types down to six that seemed to be associated with the functions of mobile apps such as public awareness measure, COVID-19 testing, quarantine monitoring, health monitoring, vaccination, and health resources (Cheng et al., 2020).

Eligibility Assessment and Selection of Apps

After initial deduplication, two independent reviewers screened mobile apps based on the identified apps' titles, keywords, and descriptions. Irrelevant apps were excluded during the preliminary screening step. After screening, the two reviewers independently assessed the eligibility of mobile apps based on the eligibility criteria. We included apps if they were: related to COVID-19; available free of cost with no in-app purchase requirement; released or updated with COVID-19 related functions during the research period; still available to users on the specified search date; developed or supported by governments or authorities; and; and full information regarding the app was accessible.

Retrieved apps from global organisations and other governments were not included. No restriction was placed on the language of the user interface and type of mobile app users. When the full description of a mobile app was not available in languages understood by the reviewers, Google Translator was used for translation. Discrepancies were resolved through discussion and a review by a third reviewer to reach a consensus.

Data Extraction and Synthesis

To develop a rubric to extract relevant data, we used a modified framework of prior studies and the CoronaNet database 5, 19. This framework covers key functions of mobile apps per codings and policy definitions by CoronaNet (Cheng et al., 2020). As a result, key functions were merged into six policy types. Definitions of main functions and lists of subordinate functions are described in Textbox 1.

Based on this framework, we developed a data extraction form using Google Spreadsheets. Two independent reviewers extracted and synthesised relevant data on the origin, platform availability (Apple App Store and Google Play Store), release date, developer, target users, uptake requirement, required technology and key functions. At each step, disagreements were resolved by consensus. In case of persistent disagreement, arbitration by the third reviewer settled the discrepancy. Descriptive statistics were used to summarise relevant information gathered from the mobile apps using R studio version 1.3.1056.

Textbox 1. Definitions of main functions (Cheng et al., 2020) and list of subordinate functions of eligible mobile apps

Public Awareness Measures: Government efforts to disseminate or gather reliable information about COVID-19

- News or government measures
- Up-to-date statistics
- COVID-19 health information
- Health management guidelines
- COVID-19 related services information
- Hotspot/risk area identification

COVID-19 Testing: Government policies to detect COVID-19 cases

- Obtain COVID-19 test
- Report of test results

Quarantine Monitoring: Targets of the policy are obliged to isolate themselves for at least 14 days because there is reason to suspect a person is infected with COVID-19

- Regular health check
- Location tracking

Health Monitoring: Government policies to monitor the health of individuals to limit the spread of COVID-19

- Digital contact tracing
- Digital check-in
- Alert contacts of COVID-19 cases
- Report suspected cases/rule infringement
- Health code/status generator
- Health/travel declaration
- Self-symptom assessment

Vaccination: Government policy made with regards to either the research and development, regulation, production, purchase and/or distribution of a given COVID-19 vaccine

- Vaccination information
- Vaccination registration/appointment
- Vaccination certificate
- Reporting adverse reactions

Health Resources: Government policies that affect the material (e.g. medical equipment, number of hospitals for public health) or human (e.g. doctors, nurses) health resources of a country

- Virtual medical consultation

- Emergency helpline
- Accessing medical records
- Personal protective equipment (PPE) distribution

Results

Selected apps

Figure 1. PRISMA flowchart of the search process.

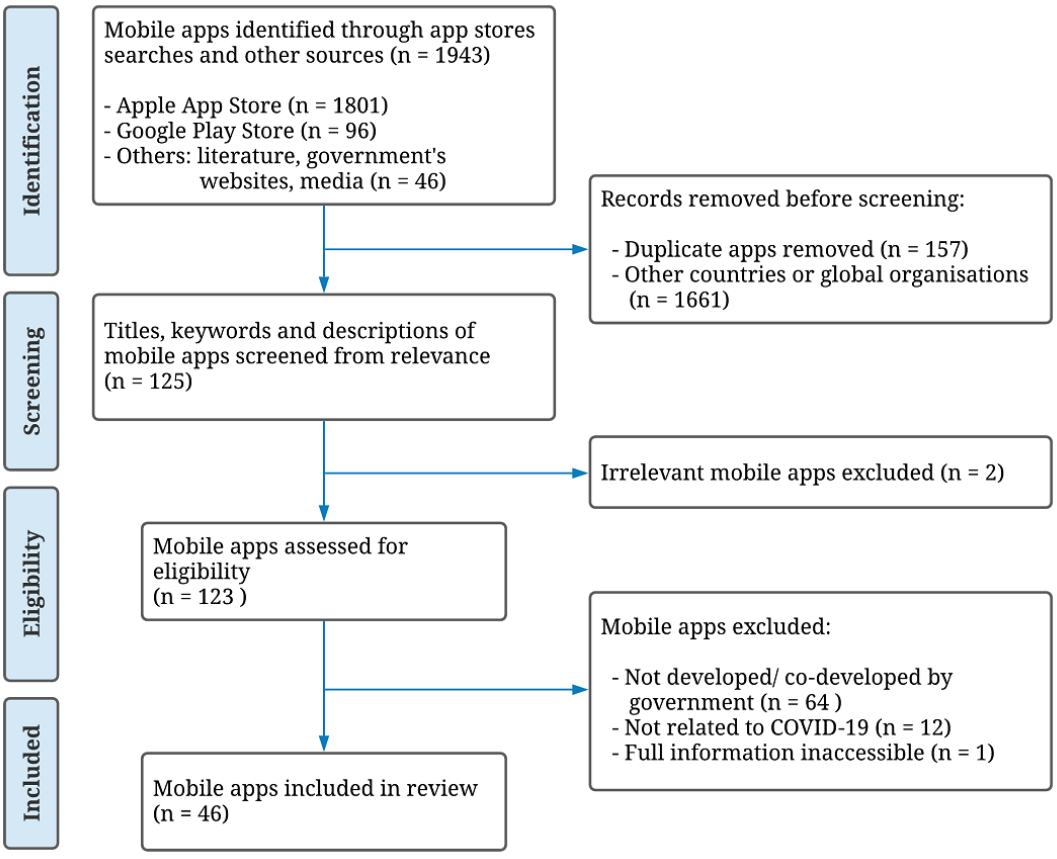


Figure 1 illustrates an overview of the process involved in selecting the apps for study synthesis. A total of 1,943 potential apps were obtained through systematic searches, of which 46 met our eligibility criteria. Although three of the apps, namely Alipay, WeChat and My

Health Bank, have pre-existed before March 2020, we included them in the review as they have since been updated to include COVID-19-related services and fit users' needs during the pandemic.

Characteristics of the Included Apps

All of the selected apps were free for users to download and use without any in-app purchase requirements. Furthermore, all of the included mobile apps were official apps developed or supported by the government and maintained by the relevant authority for COVID-19-related service provision. Descriptive analytics related to the characteristics of the apps were summarised and presented in Table 1. Most of the apps (n=9, 19.6%) come from Vietnam, followed by Malaysia, Singapore, and Thailand, with six apps each. Almost 98% of the apps were available on both iOS and Android platforms through the Apple App Store and Google Play Store.

Of all, 24 eligible apps (52.2%) were mandatory, with a mandate for target users to install them on their smartphones to be used during this pandemic. Mainly, they were mandatory for a subset of the population only, for example, people living in high-risk areas with tight pandemic restrictions and confirmed or suspected COVID-19 cases.

A majority of these apps (n=32, 69.6%) were intended for the general public. Six apps (13.0%) were especially intended for quarantined people: four apps (8.7%) for quarantined residents and two apps (4.4%) for quarantined inbound travellers. Six apps (13.2%) targeted travellers: domestic and overseas travellers (4.4%), overseas travellers including those who required quarantine (6.6%), and outbound travellers (2.2%). Overall, Global Positioning System (GPS) was the most required technology (n=28, 60.9%), followed by Bluetooth (n=16, 34.8%) and QR scanner (n=16, 34.8%). Artificial Intelligence (AI), Application Programming Interface (API) and facial-recognition technology were also utilised in three apps (n=3, 6.5%). Details of apps with their associated characteristics currently available across 11 governments included in this review are described in Table S2 in the Multimedia Appendix.

Table 1. Overview of the included apps (N=46).

Origin, n(%)		
	China	2 (4.4)
	Hong Kong	3 (6.5)

	Indonesia	3 (6.5)
	Japan	4 (8.7)
	Malaysia	6 (13.0)
	Philippines	1 (2.2)
	Singapore	6 (13.0)
	South Korea	3 (6.5)
	Taiwan	3 (6.5)
	Thailand	6 (13.0)
	Vietnam	9 (19.6)
Platform, n(%)		
	iOS (App Store)	45 (97.8)
	Android (Google Play Store)	46 (100)
Uptake requirement, n(%)		
	Mandatory	24 (52.2)
	Voluntary	22 (47.8)
Target users, n(%)		
	General public	32 (69.6)
	Travellers – domestic and overseas	2 (4.4)
	Travellers – overseas	1 (2.2)
	Travellers – quarantine	2 (4.4)
	Travellers – outbound	1 (2.2)
	Foreign workers	1 (2.2)
	Quarantined individuals	4 (8.7)
	Business owners	1 (2.2)
	Vaccinated individuals	2 (4.4)
Required technology, n(%)		
	GPS[a]	28 (60.9)
	Bluetooth	16 (34.8)
	QR scanner	16 (34.8)

	Others[b]	3 (6.5)

Table 2 - GPS[a]: the Global Positioning System, Others[b]: Artificial Intelligence (1), exposure notification API (1), facial recognition (1)

Functions of Included Apps

Overall, 25 common functions were identified, and they were subsequently organised into six overarching domains that characterised the functions of these apps, as shown in Table 2. The functions supported by each app are detailed in Table S3 in the Multimedia Appendix.

Table 2. Main functions and subordinate functions of the included apps (N=46).

Main functions and subordinate functions		N (%)
Public awareness measures		19 of 46 (41.3)
	News or government measures	12 (7.1)
	Up-to-date statistics	10 (5.9)
	COVID-19 health information	9 (5.3)
	Health management guidelines	9 (5.3)
	COVID-19 related services information	9 (5.3)
	Hotspot/risk area identification	5 (3.0)
COVID-19 testing		9 of 46 (19.6)
	Obtain COVID-19 test	4 (2.4)
	Report of test results	7 (4.1)
Quarantine monitoring		12 of 46 (26.1)
	Regular health check	5 (3.0)
	Location tracking	10 (5.9)
Health monitoring		32 of 46 (69.6)
	Digital contact tracing	11 (6.5)
	Digital check-in	11 (6.5)
	Alert contacts of COVID-19 cases	12 (7.1)

	Report suspected cases/rule infringement	5 (3.0)
	Health code/status generator	7 (4.1)
	Health/travel declaration	7 (4.1)
	Self-symptom assessment	8 (4.7)
Vaccination		7 of 46 (15.2)
	Vaccination information	4 (2.37)
	Vaccination registration/appointment	3 (1.8)
	Vaccination certificate	4 (2.4)
	Reporting adverse reactions	1 (0.6)
Health resources		12 of 46 (26.1)
	Virtual medical consultation	4 (2.4)
	Emergency helpline	7 (4.1)
	Accessing medical records	1 (0.6)
	Personal protective equipment (PPE) distribution	4 (2.4)
Total		169 (100)

The most common function served by the apps was health monitoring (n=32, 69.6%). Of these 32 apps, 11 apps were used for digital contact tracing by tracking, documenting, and retaining mobile phone users' encounters with other devices using Bluetooth or GPS. Also, 12 apps had the function of alerting contacts COVID-19 cases. If one of the app users contracted COVID-19, authorities with access to the data could request the infected user to upload the relevant anonymised data for analysis so that others with the same installed app who were in close contact may be alerted for further actions. Eleven apps served the digital check-in function with the same goal for contact tracing: keeping an efficient digital log of visitors so that officials could quickly reach out to those who might have been in close contact with a COVID-19 case present in the same events or premises.

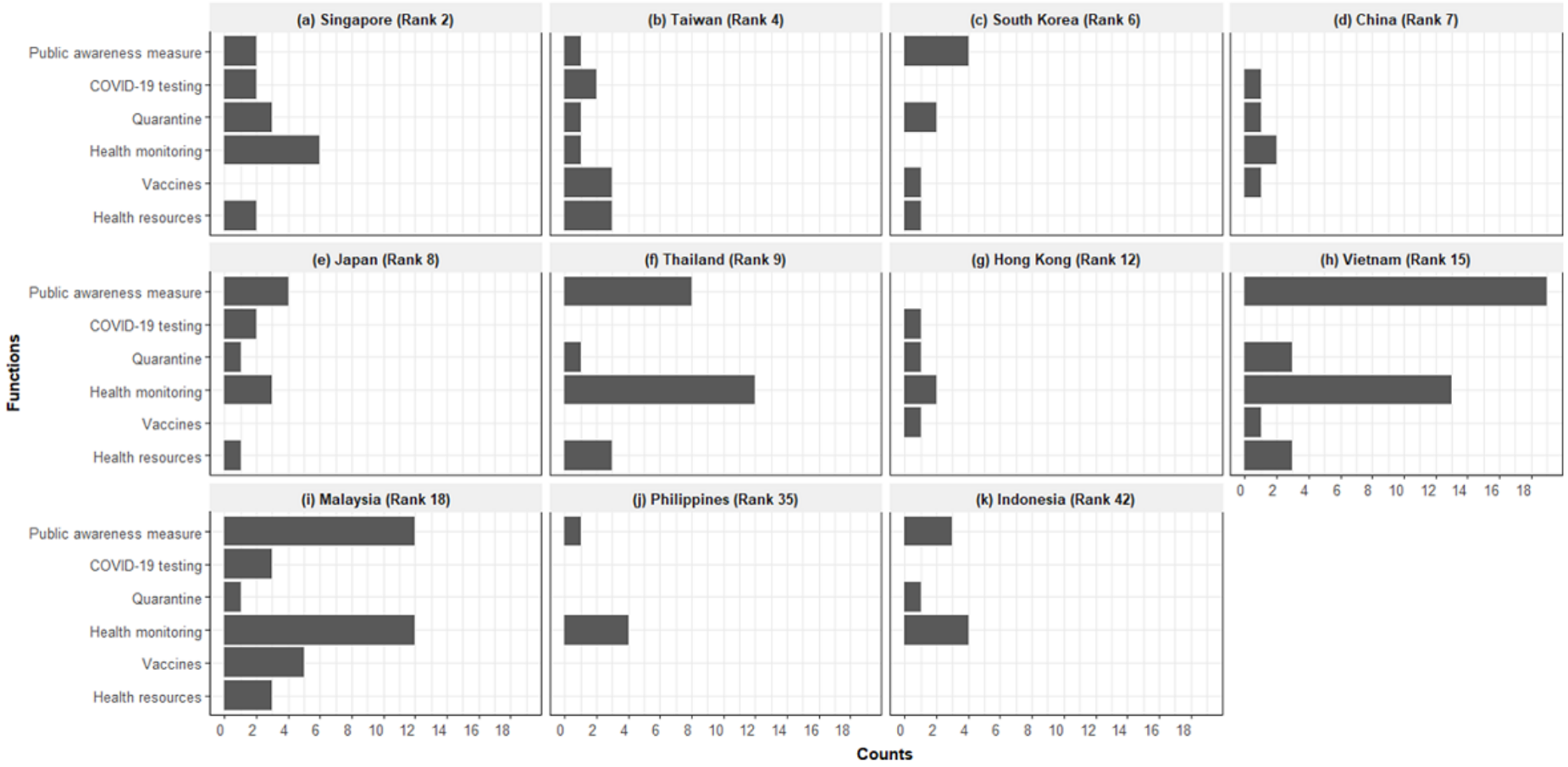
The second most common function associated with the apps was public health awareness (n=19, 41.3%). More than half of these apps were developed to provide health information and advice about COVID-19, disseminate the latest news, statistics and guidelines, and share the location and helpline number of facilities offering services during this pandemic. In addition,

some apps (n=5) provided maps of hot spots or high-risk areas with increased COVID-19 transmission to inform the public of their travel plans better.

Seven (15.2%) apps supported the function for COVID-19 vaccination. Most of these apps provided information on COVID-19 vaccines or issued digital proof-of-vaccination to app users who have completed their vaccine doses. Users could also register and make appointments for COVID-19 vaccination via the app. However, only one of the apps, the Taiwan V-watch, allowed users to report adverse reactions associated with vaccination.

Figure 2 illustrates the total number of functions served by mobile apps in each government by adding up the number of functions of each app per government. For example, if a government introduced multiple mobile apps having the same functions, the total number of functions will be the sum of each function. In general, most eligible apps had at least two different functions; otherwise, there were other complementary apps. Mobile apps in Taiwan and Malaysia had all main functions related to six different policy types, and those in Singapore and Japan covered most of the functions except for vaccination. Mobile apps in Thailand, Vietnam and Malaysia focused on functions for public awareness measures and health monitoring. Amongst these apps, the MySejahtera app from Malaysia was the most comprehensive , incorporating public awareness measures, quarantine monitoring, health monitoring, vaccination, and health resources. However, the types of functions served by mobile apps were relatively limited in the Philippines and Indonesia in comparison with the selected governments from the top 20 economies in Bloomberg's Covid Resilience Ranking.

Figure 2. Overview of the key functions of included apps by governments.



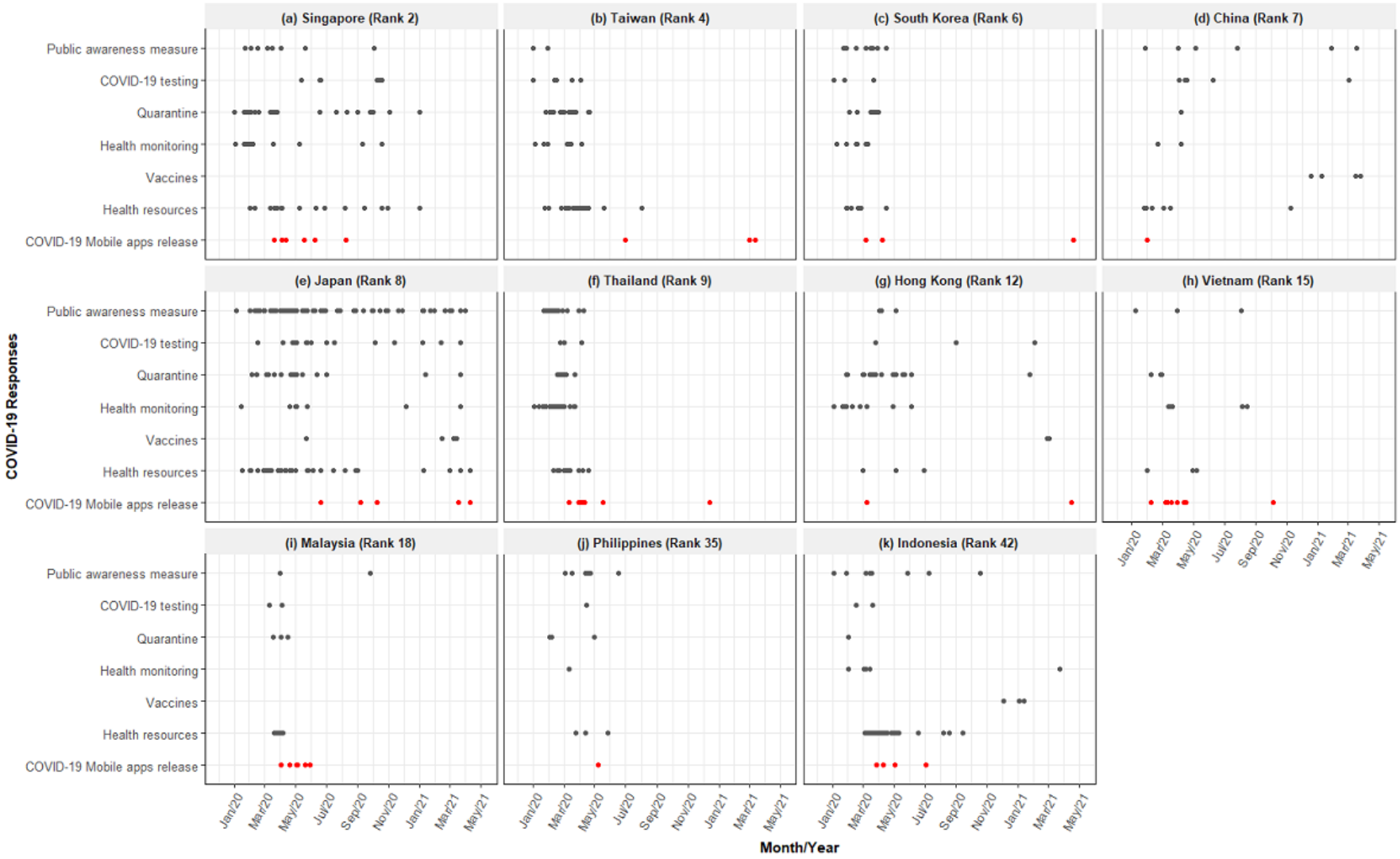
Relations between government measures and availability of mobile apps

Figure 3 shows the timeline of public health policies' commencement dates and release dates of mobile apps. Each policy type consists of subtypes, and each point indicates the timepoints of when the policies were started. We did not examine the details of each policy.

All governments introduced mobile apps to support COVID-19 mitigation policies. There were no significant differences amongst the included governments concerning when mobile apps were introduced. Also, there was no consistency in the introduction of mobile apps and the initiation of certain types of policies across the governments. Eight governments, namely Singapore, South Korea, China, Thailand, Hong Kong, Vietnam, Malaysia, and Indonesia, launched their first apps between March and April 2020. (Figure 3).

In 2021, Hong Kong, Taiwan and South Korea released apps to help track COVID-19 vaccinations, registrations, and side-effect monitoring. Some apps such as WeChat (China), MySejahtera (Malaysia), Selangkah (Malaysia) and Bluezone (Vietnam) were updated to include vaccination-related functions.

Figure 3. Governments COVID-19 policy commencement dates and release dates of the included apps.



Discussion

Principle Results

This study identified 46 mobile apps developed or supported by the 11 governments in the East and South-East Asian region using a systematic search method. We found that the East and South-East Asian governments have actively adapted to mobile health-based measures in disseminating information, tracking and tracing cases, and monitoring positive cases since March 2020. This finding is in line with a previous study reviewing 114 apps in 46 governments comprehensively in early May 2020 (Collado-Borrell, Escudero-Vilaplana, Villanueva-Bueno, Herranz-Alonso, & Sanjurjo-Saez, 2020). This study showed that most apps initially focused on disseminating information or monitoring high-risk areas and later started having functions for contact tracing. However, since the study was conducted, as our review showed, more countries have opted for initiatives using mobile platforms and expanded their apps' functions such as digital check-in, self-assessment of symptoms, virtual medical consultation, testing, and vaccination-related processes.

Unlike a recent review, we found that mobile apps integrating various functions have emerged (Alanzi, 2021). This change might be due to governments' efforts to address the users' evolving needs and to increase data management efficiency by health authorities (Oxford Business Group, 2020; Steinberg, 2020). Some governments such as Japan, Malaysia, and Vietnam have developed city-level or state-level apps which provided area-specific information which supported the local health systems. Given the necessity of crisis management at subnational levels, app-based measures can be promising by promoting regional coordination (OECD, 2020).

The leading function of the apps was health monitoring, including digital contact tracing, digital check-in, health code/status generator, health/travel declaration and self-symptom assessment. Most governments require travellers from overseas to use their apps for health declaration and monitoring (Du, Raposo, & Wang, 2020). Notably, most quarantine monitoring apps were mandatory for people who required quarantine, mainly overseas travellers. However, compulsory use of these apps would not be simple to implement, considering national or regional policies regarding data protection and privacy (Oliver et al., 2020). Indeed, data security and sharing of data with third parties have been the main reason behind the reluctance to share information in apps (Chan & Saqib, 2021; Du et al., 2020), and public trust towards

authorities is a significant reason to decide privacy trade-offs (Cho, Ippolito, & Yu, 2020). Hence, to maximise the effectiveness of the apps, there must be coordinated global, national and regional legal and ethical governance in place to confer protection against invasion of users' privacy (Zwitter & Gstrein, 2020).

We compared the timing of the rollout of mobile apps to understand how public health policy backgrounds were connected to digital solutions. All governments included in this review prepared mobile apps to support the COVID-19 mitigation policies. Most apps first emerged close to the relevant policy commencement dates between March and April 2020, and those from more successful countries tended to have diverse functions covering various governmental mitigation measures. Although governments that showed successful performance tended to introduce COVID-19 apps in the early stages of the pandemic, the COVID-19 resilience ranking did not exactly follow this trend. Therefore, having mobile apps alone does not appear to be sufficient to have a resilient COVID-19 response. This is reasonable because governmental responses for COVID-19 containment did not entirely rely on mobile apps; but instead, multifaceted approaches were utilised. The mobile apps were not a substitute for bricks-and-mortar healthcare but were integrated to complement and enhance a functioning health system. For example, Taiwan did not have a particular app for monitoring quarantine; however, it initiated the "Entry Quarantine System". This system was achieved by scanning the QR code directly or clicking on its website, wherein travellers were required to make an online health declaration within two days before arriving in Taiwan and complete a 14-day quarantine at a government facility, a designated hotel or home (Taiwan, 2020). While mobile apps have aided governments in their response to COVID-19, mobile apps alone did not appear to be sufficient to have a resilient COVID-19 response. Our finding demonstrated that the effectiveness of mobile apps, or other digital solutions, can be synergistic when the government's policies support them.

As the recent rollout of COVID-19 vaccines changes the pattern of COVID-19 resilience, there have been some attempts to expand the functions of COVID-19 apps to cover vaccination-related purposes. Mobile apps can play a huge role in educating the public about COVID-19 vaccines and improve public opinion regarding the benefits of vaccination. Mobile apps can be used to screen eligible individuals for earlier invitations to vaccinate, send reminders for vaccination appointments, and keep a record of the side effects of the vaccines. By removing the need for paper-based documents, digital vaccination certificates can be issued and stored

electronically through mobile apps (EC, 2021). Thus, it might be a critical tool in helping to lessen the restricted movement caused by this pandemic (EC, 2021; Kelleher, 2021).

None of the apps in our review was explicitly used for conducting research purposes. Mobile apps can be designed to recruit volunteers for COVID-19-specific studies and obtain informative data such as the long-term effects of SARS-CoV-2 infection or adverse reactions of COVID-19 vaccination. We believe that there is an enormous potential for such apps, especially among researchers in public health or health economics. Mobile app-based population surveys can be a quick, cost-effective way to collect and generate research data to improve our understanding and response to this pandemic. Therefore, increased effort from governmental organisations is required to promote the development and utilisation of digital solutions in scientific studies.

Limitations

This study has its limitations that are important to acknowledge. Despite endeavouring to search mobile apps as many as possible, it is plausible that some apps may have also been missed due to the restrictive setting of several regional app stores. To overcome this issue, we have scoured other sources of information such as current news articles, media reports and literature to find additional relevant apps. However, it is still likely that some relevant apps were missed as our search terms may not cover all the available apps, especially those named in the local languages.

Moreover, we did not collect data on the consumer ratings or user feedback of each app. We also neither examined the popularity nor took into account the number of downloads of the apps. Although some evidence suggests that contact-tracing apps should be adopted by at least 60-70% of the population to impact the outbreak transmission rate, much lower app penetration could still be substantial in breaking transmission chains and preventing infection (Hart et al., 2020; O'Neill, 2020; University of Oxford, 2020).

Lastly, we did not examine the mobile uptake proportion by people from different socioeconomic backgrounds. Given that mobile apps may not be accessible to the most deprived at the bottom of the social ladder, future studies should consider the impact of COVID-19 measures relying on mobile apps for marginalised groups, including the elderly, the homeless, immigrants, and rural residents (Beaunoyer, Dupéré, & Guitton, 2020; Lee,

Rogers, & Braunack-Mayer, 2008; Van Lancker & Parolin, 2020), and consider including data protection policy and popularity of the app.

Conclusion

In conclusion, our findings added knowledge on the COVID-19-related apps used in 11 governments in the East and South-East Asian regions. The most common function was to monitor public health, followed by disseminating information and health education. Most apps deployed GPS, followed by Bluetooth and QR scanner technologies. Most countries in this region adopted mobile apps to support COVID-19 mitigation efforts and introduced them close to the relevant policy commencement dates in the early stages of the pandemic. In addition, some governments which are relatively successful in suppressing COVID-19 tended to have all-in-one mobile apps or other complementary mobile apps. Therefore, mobile apps in East and South-East Asian regions have pivotal roles in supporting governments' measures for tracking COVID-19 cases and delivering credible information.

Conflicts of Interest

This study received no specific grant from any agency. The authors declare no conflict of interest for this work.

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Appendix

Table S1. List of selected countries or regions with their scores based on Bloomberg's Covid Resilience Ranking (March 2021) *

Rank	Country/ Region	Bloomberg's Covid Resilience Score	COVID status						Quality of life			
			1-month cases per 100,000	1-month fatality rate	Total deaths per 1 m	Positive test rate	Vaccination rate	Lockdown severity	Community mobility	2021 GDP growth forecast	Universal Healthcare coverage	Human development index
2	Singapore	76.6	6	0.3%	5	0%	9.4%	51	-11.3%	5.9%	92	0.94
4	Taiwan	73.5	0	1.6%	0	0.7%	0.1%	25	-6.8%	4.3%	79	0.91
6	South Korea	69.7	22	1.1%	33	1.3%	0.7%	58	-4.6%	3.4%	89	0.92
7	China	68.4	0	0%	3	0.1%	2.7%	57	-19.5%	8.5%	70	0.76
8	Japan	68	24	4%	70	2.5%	0.3%	43	-13.2%	2.8%	96	0.92
9	Thailand	67	4	0.3%	1	0.7%	0.1%	47	-0.2%	3.5%	72	0.78
12	Hong Kong (SAR)	66.2	7	1.2%	27	0.1%	2.6%	71	-14.6%	4.1%	-	0.95
15	Vietnam	64.2	0	0%	0	0.1%	0.1%	63	-10.8%	7.5%	60	0.70
18	Malaysia	61.1	135	0.4%	38	2.7%	0.7%	68	-22.7%	5.5%	67	0.81
35	Philippines	51.9	102	0.8%	119	13.6%	0.2%	79	-29.9%	7.5%	55	0.72
42	Indonesia	49	60	2.8%	146	13.7%	1.6%	69	-21.8%	4.8%	49	0.72

*from Hong, Chang, & Verley, 2021

Table S2. List of mobile apps included in the study with their associated characteristics

Country/ region of origin	Name of App	Platform		Date of release/ Date of update	Developer/ owner	Uptake requirement	Target users	Required technology
		iOS	Android					
China	Alipay Health Code	√	√	February 2020	Alipay (Hangzhou) Technology Co., Ltd	Mandatory	General public	GPS, QR scanner
China	Wechat Health Code	√	√	February 2020	WeChat	Mandatory	General public	GPS, QR scanner
Hong Kong	StayHomeSafe	√	√	March 2020	Government of Hong Kong SAR	Mandatory	Quarantined individuals	GPS, QR scanner
Hong Kong	QR Code Verification Scanner	√	√	April 2021	Food and Environmental Hygiene Department	Voluntary	Business owners	QR scanner
Hong Kong	LeaveHomeSafe	√	√	November 2020	Government of Hong Kong SAR	Mandatory	General public	GPS, QR scanner
Japan	COCOA - COVID-19 Contact	√	√	June 2020	Ministry of Health, Labour and Welfare of Japan	Voluntary	General public	Bluetooth, Exposure Notification API
Japan	Chofu City Corona Information	√	√	September 2020	Chofu City	Voluntary	General public	N/A
Japan	Overseas Entrants Locator (OEL)	√	√	March 2021	Emergency Assistance Japan Co., Ltd.	Mandatory	Quarantined overseas traveller	GPS
Japan	TeCOT	√	√	April 2021	Ministry of Economy, Trade and Industry	Voluntary	Outbound travellers	N/A
Malaysia	MySejahtera	√	√	April 2020	Government of Malaysia	Mandatory[a]	General public	GPS, QR scanner
Malaysia	Qmunity	√	√	April 2020	Sarawak Digital Economy Corporation Berhad	Voluntary	General public	GPS, QR scanner Facial recognition,
Malaysia	COVIDTrace Sarawak	√	√	May 2020	Sarawak State Government	Voluntary	General public	QR scanner Bluetooth,

Country/ region of origin	Name of App	Platform		Date of release/ Date of update	Developer/ owner	Uptake requirement	Target users	Required technology
		iOS	Android					
Malaysia	Jejak Johor	√	√	May 2020	Johor State Government	Voluntary	General public	Bluetooth
Malaysia	MyTrace	√	√	May 2020	Ministry of Science, Technology and Innovation	Voluntary	General public	Bluetooth
Malaysia	SELANGKAH	√	√	May 2020	Selangor State Government	Voluntary	General public	GPS, QR scanner
South Korea	Self Quarantine Safety Protection	√	√	March 2020	Ministry of the Interior and Safety	Mandatory	Quarantined overseas travelers	GPS, Bluetooth
South Korea	COVID-19 Guidelines Search	√	√	April 2020	Seoul Public Health and Medical Foundation	Voluntary	General public	N/A
South Korea	COOV	√	√	April 2021	Korea Disease Control and Prevention Agency and Blockchain Labs	Mandatory	Vaccinated individuals	N/A
Singapore	TraceTogether	√	√	March 2020	Ministry of Health and Government Technology Agency (GovTech)	Mandatory	General public	GPS, Bluetooth
Singapore	Homer	√	√	April 2020	Government Technology Agency (GovTech)	Mandatory	Quarantined individuals	GPS
Singapore	OneService	√	√	April 2020	Ministry of National Development	Voluntary	General public	GPS
Singapore	FWMOMCare	√	√	May 2020	Ministry of Manpower (MOM)	Mandatory	Foreign workers	GPS
Singapore	SafeEntry QR Scanner	√	√	June 2020	Government Technology Agency (GovTech)	Mandatory	General public	QR scanner
Singapore	StayHome@SG	√	√	August 2020	Immigration & Checkpoints Authority	Mandatory	Quarantined individuals	GPS, QR scanner
Taiwan	My Health Bank	√	√	July 2020	Taiwan National Health Insurance Administration	Voluntary	General public	GPS

Country/ region of origin	Name of App	Platform		Date of release/ Date of update	Developer/ owner	Uptake requirement	Target users	Required technology
		iOS	Android					
Taiwan	Taiwan V-watch Via LINE app	√	√	March 2021	Taiwan Centers for Disease Control	Voluntary	Vaccinated individuals	N/A
Taiwan	Taiwan Social Distance	√	√	March 2021	Taiwan Centers for Disease Control	Voluntary	General public	Bluetooth
Thailand	H4U-COVID19	√	√	March 2020	Ministry of Health	Voluntary	General public	N/A
Thailand	SydeKick for ThaiFightCOVID	√	√	March 2020	Ministry of Digital Economy and Society and the Ministry of Public Health	Mandatory[c]	Quarantined overseas travelers	GPS, Bluetooth
Thailand	MorChana	√	√	April 2020	Digital Government Development Agency (DCD)	Mandatory[b]	General public	GPS, QR scanner Bluetooth
Thailand	Card2U	√	√	April 2020	Ministry of Digital Economy and Society	Voluntary	General public	GPS
Thailand	Thai Chana	√	√	May 2020	Krungthai Bank	Mandatory[b]	General public	QR scanner
Thailand	ThailandPlus	√	√	December 2020	Ministry of Digital Economy and Society and the Prime Minister's Office	Mandatory	Overseas travelers	GPS, QR scanner Bluetooth
Vietnam	Vietnam Health	√	√	February 2020	Viettel Information and Communications Technology Solutions Center	Voluntary	General public	N/A
Vietnam	Vietnam Health Declaration	√	√	March 2020	Vietnam Ministry of Health Office	Mandatory	Domestic and overseas travelers	GPS, QR scanner Bluetooth
Vietnam	COVID-19	√	√	March 2020	International Joint Stock Company (AIC Group) and Electronic Health Administration - Ministry of Health	Voluntary	General public	GPS
Vietnam	Hanoi SmartCity	√	√	March 2020	Hanoi Informatics Centre and Hanoi Centre	Mandatory[d]	General public	GPS

Country/ region of origin	Name of App	Platform		Date of release/ Date of update	Developer/ owner	Uptake requirement	Target users	Required technology
		iOS	Android					
Vietnam	NCOVI	√	√	March 2020	Ministry of Information and Communications and Ministry of Health	Voluntary[e]	General public	GPS, Bluetooth
Vietnam	Ncovi Gia Lai	√	√	March 2020	Information Technology and Communication Center of Gia Lai Province	Voluntary	General public	GPS
Vietnam	Bluezone-Contact detection	√	√	April 2020	Ministry of Information and Communications and Ministry of Health	Mandatory	General public	Bluetooth
Vietnam	CoviTrack	√	√	April 2020	Vietnam Ministry of Health Office	Voluntary	General public	Bluetooth
Vietnam	An toàn COVID19	√	√	October 2020	Ministry of Education and Training	Mandatory	General public	GPS
Indonesia	PeduliLindungi (Care amd Protect)	√	√	March 2020	Ministry of Communication and Information Technology	Mandatory[f]	General public	GPS, Bluetooth
Indonesia	10 Rumah Aman		√	March 2020	The President's Staff Office and Ministry of Communication and Information Technology	Voluntary	General public	GPS, Artficial Intelligence
Indonesia	eHAC	√	√	April 2020	Ministry of Health (Kemenkes) Republic of Indonesia	Mandatory	Domestic and overseas travelers	GPS
Philippines	StaySafe PH	√	√	May 2020	Multisys Technologies Corporation	Mandatory	General public	QR scanner, Bluetooth

Table S3. List of mobile apps included in the study with their associated functions

	Public Awareness Measures						COVID-19 Testing		Quarantine Monitoring		Health Monitoring							Vaccination				Health Resources			
App Name	News or government measures	Up-to-date statistics	COVID-19 health information	Health management guidelines	COVID-19 related services information	Hotspot/risk area identification	Obtain COVID-19 test	Report of test results	Regular health check	Location tracking	Digital contact tracing	Digital check-in	Alert contacts of COVID-19 cases	Report suspected cases/rule infringement	Health code/status generator	Health/travel declaration	Self symptom assessment	Vaccination information	Vaccination registration/appointment	Vaccination certificate	Reporting adverse reactions	Virtual medical consultation	Emergency helpline	Accessing medical records	Personal protective equipment (PPE) distribution
Alipay Health Code										Y					Y	Y									
Wechat Health Code								Y							Y	Y				Y					
LeaveHomeSafe								Y				Y	Y												
StayHomeSafe										Y															
QR Code Verification Scanner																		Y							
COCOA - COVID-19 Contact								Y			Y		Y												
Overseas Entrants Locator (OEL)										Y		Y													
TeCOT					Y		Y																		Y
Chofu City Corona Information	Y	Y	Y																						
COVIDTrace Sarawak		Y						Y			Y	Y	Y												
Jejak Johor											Y		Y												
MySejahtera	Y	Y	Y	Y	Y	Y			Y			Y			Y	Y	Y	Y	Y	Y		Y	Y		

	Public Awareness Measures						COVID-19 Testing		Quarantine Monitoring		Health Monitoring							Vaccination				Health Resources			
App Name	News or government measures	Up-to-date statistics	COVID-19 health information	Health management guidelines	COVID-19 related services information	Hotspot/risk area identification	Obtain COVID-19 test	Report of test results	Regular health check	Location tracking	Digital contact tracing	Digital check-in	Alert contacts of COVID-19 cases	Report suspected cases/rule infringement	Health code/status generator	Health/travel declaration	Self symptom assessment	Vaccination information	Vaccination registration/appointment	Vaccination certificate	Reporting adverse reactions	Virtual medical consultation	Emergency helpline	Accessing medical records	Personal protective equipment (PPE) distribution
MyTrace											Y														
Qmunity		Y				Y						Y													
SELANGKAH	Y				Y	Y	Y	Y				Y							Y	Y					Y
Self Quarantine Safety Protection				Y					Y	Y													Y		
COOV																				Y					
COVID-19 Guidelines Search	Y		Y	Y																					
FWMOMCare	Y				Y		Y	Y				Y					Y					Y			Y
Homer									Y	Y															
OneService														Y											
SafeEntry QR Scanner												Y													

	Public Awareness Measures					COVID-19 Testing		Quarantine Monitoring			Health Monitoring							Vaccination				Health Resources			
App Name	News or government measures	Up-to-date statistics	COVID-19 health information	Health management guidelines	COVID-19 related services information	Hotspot/risk area identification	Obtain COVID-19 test	Report of test results	Regular health check	Location tracking	Digital contact tracing	Digital check-in	Alert contacts of COVID-19 cases	Report suspected cases/rule infringement	Health code/status generator	Health/travel declaration	Self symptom assessment	Vaccination information	Vaccination registration/appointment	Vaccination certificate	Reporting adverse reactions	Virtual medical consultation	Emergency helpline	Accessing medical records	Personal protective equipment (PPE) distribution
StayHome@SG										Y															
TraceTogether											Y		Y												
My Health Bank					Y		Y		Y													Y		Y	Y
Taiwan V-watch via LINE																		Y	Y		Y				
Taiwan Social Distance								Y					Y												
Mor Chana											Y	Y	Y		Y		Y								
ThailandPlus											Y	Y	Y		Y										
Card2U	Y	Y	Y		Y	Y																	Y		
H4U-COVID19	Y			Y		Y											Y								
SydeKick for ThaiFightCOVID										Y													Y		
Thai Chana												Y	Y										Y		
An toàn COVID19															Y		Y								

	Public Awareness Measures						COVID-19 Testing		Quarantine Monitoring		Health Monitoring							Vaccination				Health Resources			
App Name	News or government measures	Up-to-date statistics	COVID-19 health information	Health management guidelines	COVID-19 related services information	Hotspot/risk area identification	Obtain COVID-19 test	Report of test results	Regular health check	Location tracking	Digital contact tracing	Digital check-in	Alert contacts of COVID-19 cases	Report suspected cases/rule infringement	Health code/status generator	Health/travel declaration	Self symptom assessment	Vaccination information	Vaccination registration/appointment	Vaccination certificate	Reporting adverse reactions	Virtual medical consultation	Emergency helpline	Accessing medical records	Personal protective equipment (PPE) distribution
Bluezone-Contact Detection											Y		Y	Y				Y							
COVID-19 (Vietnam)	Y	Y	Y	Y	Y											Y						Y			
CoviTrack											Y														
Hanoi SmartCity	Y								Y	Y															
NCOVI	Y	Y	Y	Y						Y				Y		Y									
Ncovi Gia Lai	Y	Y	Y	Y										Y									Y		
Vietnam Health	Y	Y	Y	Y	Y									Y			Y						Y		
Vietnam Health Declaration																Y									
PeduliLindungi										Y	Y		Y												
10 Rumah Aman			Y	Y	Y												Y								
eHAC																Y									
StaySafe PH		Y									Y		Y		Y		Y								
Total	12	10	9	9	9	5	4	7	5	10	11	11	12	5	7	7	8	4	3	4	1	4	7	1	4

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