Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Lessons on mobile apps for COVID-19 from China

Sophia L. Zhou a,b,c, Xianhan Jia a, Samuel P. Skinner a, William Yang a, Isabelle Claude c,d

a Mass Academy of Math and Science, Worcester Polytechnic Institute, 85 Prescott Street, Worcester, MA 01605, United States
b Department of Computer Science, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA 01609, United States
c Department of Physics, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA 01609, United States
d Department of Biomedical Engineering, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA 10609, United States

A R T I C L E   I N F O

Keywords:
Mobile apps
COVID-19 response
Survey
Interview
Lessons

A B S T R A C T

The COVID-19 pandemic has impacted the global society and human life profoundly. Many countries have launched COVID-19 mobile apps with a wide range in how these apps work. While it is hoped that these apps can assist in the fight against COVID-19, many are worried about user privacy. China implemented “health code” systems, which assigned neighborhoods and citizens a specific health code, meant to indicate their risk of having been exposed to COVID-19. The most widely used health code systems were hosted on the popular apps WeChat and Alipay, each with billions of users. Some experts argued that China’s use of mobile applications was essential to its successful combat against COVID-19.

Included in this study are a summary of mobile technology usage in China, a review of previous studies of mobile technology in healthcare, and a brief survey of some existing mobile applications for COVID-19 that were implemented. Also included are outcomes of interviews with healthcare and public safety experts and a public survey to understand how mobile applications were used in China’s response to COVID-19. The interviews revealed four important themes: personal privacy, community involvement, government involvement, and situational specificity. It was found that a key concern was maintaining a balance between collecting and utilizing personal information, as well as protecting this information. In addition, close collaboration between local communities and the national government was essential. Mobile applications assisted in communication and coordination but did not replace the work of people such as delivery drivers and contact tracers. Our results also showed that there was room for improvement, especially accessibility for the elderly or those unfamiliar with technology.

Similar results were obtained from our survey. It was interesting to find that the apps were mostly used for “accessing information on COVID-19.” In addition, respondents overwhelmingly identified “information” as the most valuable feature of COVID-19 apps. Both interview and survey results revealed the importance of providing information as a primary function of COVID-19 apps.

Based on our findings we distilled four main lessons: mobile applications should assist in existing COVID-19 responses, inform users, protect users’ personal information, and adapt to users’ environments.

We recommend that public health officials and app developers take these lessons into consideration when developing COVID-19 related mobile applications. In addition, we encourage researchers to utilize this report as a jumping off point for further research.

1. Introduction

The pandemic of COVID-19 reminds us that, while globalization has certainly improved living standards in many parts of the world, the increased mobility of people and products has also made the spread of diseases like the COVID-19 easier. It is clear that developing useful tools to effectively mitigate the spread of diseases is an important task. One tool that holds promise is mobile technology. While there is an existing body of research around mobile solutions to infectious diseases, the rapid advancements in mobile technology, including cloud computing and big data, means that radically different situations may be developed over a short period of time. One fairly new form of mobile technology that has been utilized heavily in China during the current COVID-19 crisis is a myriad of mobile applications that assist citizens and authorities in tracking and containing the spread of COVID-19. In order to better understand how these programs function and how they can be made more effective in the future, the authors conducted interviews with healthcare and public...
safety experts and a public survey to understand the end users’ perspective on these mobile apps.

Many doctors and health officials believe that the only long-term solution to the COVID-19 crisis is the development of a vaccine for SARS-CoV-2, which experts hope may be available in mid-2021 [1]. Currently, it is widely accepted that extensive testing and effective contact tracing are essential to mitigation of the continuous spreading of COVID-19 while waiting for the vaccine.

The use of the “Health Code” system in China’s response to COVID-19 generated much interest worldwide. Seen by some as a draconian control-measure; others have argued that the health code system, which works through mobile applications on citizens’ phones, has been integral to China’s success during the COVID-19 crisis [2]. Though the health code system was originally hosted on its own app, it is now being held as a mini-program on the popular Chinese apps WeChat and Alipay [3]. The rapid implementation of these apps is directly connected to the widespread usage of smartphones throughout China and the rest of the world.

1.1. The ubiquity of mobile technology in China

Over the past ten years, the usage of mobile technology, typified by devices such as smartphones, tablets, and laptops, has spread rapidly around the globe. According to a Pew Research Foundation study, it is estimated that over five billion people, over 60 percent of the world population, have mobile devices [4]. Statista.com estimated that there are over 877 million mobile phone users in China in 2019 [5]. Information on Statista.com anticipates that the number of smartphone users will increase by two percent by 2021, and will continue to rise each year by two percent [6]. This rise in smartphone use is part of a long-standing trend. Younger people are especially more likely to be digitally connected. One survey found that over 90 percent of respondents in advanced economies under the age of 35 owned a smartphone [4]. It is also important to note that, although a great many in China uses mobile technology, its usage is not equal across the nation. Laura Silver of Pew Research found that people in advanced economies, or people with higher levels of education, are more likely to have smartphones than people in emerging economies [4].

For the past few years China has been attempting to build a cashless society, with apps like WeChat and Alipay serving as mediums through which transactions can flow [7]. Both Alipay and WeChat having over a billion users in 2019 (18,9). The COVID-19 crisis has hastened China’s move towards a cashless society, as people look for ways to safely purchase things without physically exchanging money [10]. The widespread usage of these apps likely meant that when the health code systems were integrated as mini-programs on Alipay and Wechat, many users were able to access the health code system without downloading any new applications.

With their wide penetration in societies, smartphones and other forms of mobile technology have become a key component in communication throughout the world, serving as an effective tool to collect data and to disseminate critical instructions and information during worldwide crises such as the current pandemic.

1.2. Mobile technology in healthcare

Over the past few decades, mobile phones and tablets have increasingly been integrated into healthcare systems around the world, and recent developments in big data analysis led to new advancements. These relatively new innovations promise to boost the efficiency of healthcare systems across the world while also improving healthcare outcomes.

Hospitals have been utilizing various forms of mobile technology to improve the efficiency of their healthcare workers and to lessen costs. These benefits were detailed in a 2008 overview by Susan and Craig Standing entitled Mobile Technology and Healthcare: The Adoption Issues and Systematic Problems ([11]). The ability for healthcare workers to update patient records at the point of care using mobile devices has decreased the amount of clerical errors. These patient records can, in turn, be accessed by healthcare workers directly from various locations. The mobile technology also enabled healthcare workers to virtually consult with one another and with their patients at the time of need, leading to a reduced patient load. The Standings’ analysis shows that the cost benefits of these technology integrations are quite stark. In one case, the integration of voice-activated, hands-free communications systems at a Sydney hospital freed up to 20 h of staff time per day, or a cost savings of seven million dollars per year. Another benefit was that much of this technology is designed to function wirelessly, cutting down on expenses associated with installing the hard wiring for machines such as PCs. In addition to the initial expense of hard wiring, repairs are frequently required, further making mobile technology the cheaper option.

Though many benefits of mobile technology assume the presence of an existing and extensive healthcare infrastructure, mobile technology is also being used to improve healthcare outcomes in historically wealth-deprived regions, such as many parts of Africa and South Asia [12]. In these regions, healthcare workers are often required to take responsibility for more patients than they can reasonably attend to, while working with significantly fewer resources than healthcare workers in wealthier countries [12]. Additionally, many of these healthcare workers must go to their patients, as opposed to their patients coming to one centralized location such as a hospital or clinic; this adds further strain on these healthcare workers, when one considers that many of the locations that they are expected to service are often distant from one another [12]. Mobile technology functions as a critical way for healthcare workers to communicate, receive training, and be deployed by managers. According to one pilot study in Mawii, the use of mobile phones allowed healthcare workers to double the number of clients they were able to service over a six-month period [13]. Another study found that midwives and associated healthcare workers in Indonesia self-reported that mobile phones made it easier for them to meet their patients’ needs on a timely basis [14].

Despite the general scholarly consensus that mobile technology can greatly improve healthcare systems in the developing and developed world alike, there are still major barriers to its full integration and use [11]. It was found that the current speed of innovation indicates that the cutting-edge technology of today could soon become obsolete, raising the need for further investment in related infrastructure. In addition, significant resistance towards utilizing mobile technology came from the culture of healthcare workers. Due to the high stakes associated with healthcare, healthcare professionals tend to have a conservative ‘if it isn’t broken, don’t fix it,’ mentality, making doctors and nurses less likely to adopt technology that they are not comfortable using, or which they perceive to have flaws. The failure of healthcare professionals to fully embrace new innovations can result in subpar results for these new systems, as the synergistic nature of mobile technology requires all aspects of a system to be utilized for maximum efficiency. However, others studies have found that, as healthcare workers have begun to utilize phones and tablets in their personal lives more often, they have increasingly brought them into the workplace, increasing the prevalence of mobile technology in healthcare in a more organic way [15]. As attitudes continue to change and mobile technology continues to evolve, the barriers to its use in the healthcare industry seem to be lowering.

Smartphones and similar devices allow public health officials to quickly share and record occurrences of infectious diseases in an area, which then allows public health officials to decide what steps to take to mitigate the spread of said disease, as well as allowing researchers to develop models for how the disease may continue to spread [16]. For example, researchers found that the data generated by mobile technology can be used to accurately predict the prevalence of HIV in a certain geographic area, enabling healthcare workers to focus their resources on those areas [17]. Similar methods of data analysis, which comb through Google searches and social media posts for keywords in relation to geography, have also been used successfully to track the
spread of influenza [18]. The combination of these two technologies has proven much more effective than earlier attempts, due to recent technological developments. Mass phone surveys were utilized to track the spread of the H1N1 virus in Mexico during the 2009 outbreak to limited success, illustrating that, in under a decade, mobile methods have gone from a somewhat effective method of disease management to an extremely effective method [19]. Further advances in big data suggest that the usefulness of these technologies in the fight against pandemics will only increase with time. Therefore, it is critical to study past and current applications of mobile technology to learn how best to utilize it during future pandemic scenarios.

1.3. Existing mobile applications for COVID-19

Though mobile technologies like phones and laptops are not new to healthcare, the wealth of mobile applications that have been deployed to fight COVID-19 is unprecedented. Mobile apps make it easier than ever for healthcare professionals to collect large amounts of location and health data at a rapid pace. Throughout the COVID-19 crisis, mobile apps have been deployed in countries including China, Switzerland, and the United States in order to assist in the fight against COVID-19 [20]. Table 1 shows some of the apps being utilized in 11 regions as of July 2020. The deployment and use of these applications have varied both among and within different countries, on a spectrum of what researchers have called a maximal and minimal approach [21].

| Country/Region                          | Name                        |
|----------------------------------------|-----------------------------|
| China                                  | Alipay/ WeChat              |
| India                                  | Aarogya Setu                |
| United States/North and South Dakota   | Care19                      |
| United States/Utah                     | Healthy Together            |
| Czech Republic                         | eRouška (eFacemask)        |
| Hungary                                | Virus Radar                 |
| Latvia                                 | Aptuti Covid                |
| Switzerland                            | DP-3T                       |
| Norway                                 | Smittestopp                 |
| Russia                                 | Social Monitoring           |

|
|
| Table 1: Examples of Mobile Apps Utilized in COVID-19 Pandemic. |

On May 21, 2020, roughly five months after the first reported cases of COVID-19, researchers at John Hopkins University released a report on the findings from a focus group of experts in mobile responses to pandemics, attempting to set guidelines for the use and deployment of mobile applications in pandemics, with a special interest in the ongoing crisis [21]. While the focus group agreed that mobile apps have the potential to greatly assist public health officials, they also emphasized that the benefit derived from the use of these apps must greatly outweigh the harm they pose, especially when it comes to the issue of privacy. Privacy concerns have also been raised over the mobile applications being used in the Hangzhou province of China, with some experts worrying that the usage of these apps will become normalized even after the pandemic is over [22]. In the United States, NPR reporter Sharon Bond raised the issue that having a company like Google or Apple collecting and reporting users’ movements to the government might be “really creepy to a lot of people” [23].

In South Korea, the location information of infected citizens is posted on government websites, blogs, and social media accounts after the citizen’s data is anonymized [24]. This practice, considered as a “maximal” approach, contrasts with practice in the United States, “which has so far erred on the side of individual privacy, and from neighboring Japan, where testing has been deliberately limited.” [24]. The United States has undertaken a “minimal” approach, with contact tracing mostly being outsourced to private companies, who collect location data, anonymize it, and then report it to participating state and federal governments [21]. For example, North Dakota’s state government has partnered with the company ProudCrowd to adapt their sports fan tracking app to be used for contact tracing during COVID-19 [25]. The governor’s office has a goal of getting 50,000 people, approximately seven percent of the state’s population, to agree to download the app, which tracks anonymized user locations in ten-minute increments, and allows users to send their own data to the state government if they become infected with COVID-19 [25]. Undoubtedly, more contact tracing apps and strategies will emerge as the COVID-19 crisis continues; developing an understanding of how these apps function, and how they manage the conflict between efficiency and privacy is important to creating better apps to assist public health officials while respecting the rights of individuals.

What should be clear from this brief discussion is that the character of COVID-19 apps often depends on the governmental structure and culture of the society in which they are deployed. Because of this fact, it is likely not possible to create a one-size-fits-all application for the whole world; however, understanding the victories and failures of contact tracing apps in one country can be useful in improving apps in another part of the world. For example, the Chinese model of contact tracing app would likely not work in the United States, due to differing cultural attitudes about personal privacy, but an examination of the Chinese model could still be very useful in improving and criticizing the American model [26].

As history and current events have shown, there is no single way to deal with a pandemic. Different countries took different measures to prevent the spread of the Coronavirus, with some being more effective than others. While there is an existing body of literature on the applications of mobile technology to prior pandemics, there is to date little analysis regarding how this rapidly evolving technology was and is being used to mitigate the spread of COVID-19 from the end users perspective. This study is aimed to help fill this gap.

2. Methodology

2.1. Expert interviews

Expert interviews were conducted among knowledgeable individuals with relevant experience and expertise in public safety, emergency science, and public health. The interview questions were developed based on background and literature research and initial discussions with expert interviewees. Each interviewee was provided with a list of possible interview questions in English and Chinese before the interview. Giving interviewee’s questions in advance allowed them to provide more accurate and detailed answers during the actual interview, increasing the usefulness of the data collected from these interactions [27]. Specifically, in our case, this also allowed interviewees who did not speak English as their native language to prepare responses in English, enabling them to take the time to create a response that may not have been possible in a fast-paced live interview. Interviews were conducted primarily in English, but a Chinese speaker was on hand to receive and ask clarifying questions in Chinese when needed. All interviews were recorded, and a transcript of the interview was constructed afterwards. These transcripts were numbered and anonymized to protect the identities of the experts. The questions were slightly revised and updated after each interview in order to collect the most relevant and useful information possible. Interviews were coded for common themes in a multi-step process. The coding technique utilized was adapted from the open-coding method as described by researchers at the University of Arizona [28]. An initial read-through of the interview transcripts was performed, where approximately twenty themes were identified, such as Trust in Government and Contact Tracing. After successive read-throughs, these twenty themes were refined into ten concise themes, where themes like Community Food Delivery and Community Check-ins were consolidated into Community Involvement. This process was continued until six themes were generated that best represented the interview data. These themes were:

- Personal Privacy
- Community Involvement
• Government Involvement
• Situational Specificity
• Strengths
• Possible Improvements

Each of these themes was coded for a unique type of information. Personal Privacy pertains to concerns and information on the collection of personal and private data on COVID-19 apps. Community Involvement and Government Involvement pertain to the differing and unique roles that the local community and government took during the COVID-19 crisis. Situational Specificity pertains to information about regional concerns and temporal concerns regarding COVID-19 apps. Strengths and Possible Improvements pertain to comments praising or criticizing certain aspects of China’s COVID-19 response and its use of mobile applications.

2.2. Public survey

A survey of multiple-choice and free-response questions was developed to collect information on user demographics, user experience, and user perception of COVID-19-related apps. The survey was developed using the survey design guidelines by Quinn Evaluation Consulting [29]. The survey questions in English and Chinese were loaded to an online surveying platform, WenJuanXing (“Survey Star” in English) for dissemination. The survey was only administered to people in China over the age of 18. The survey link was disseminated through multiple mailing lists and social media platforms including Wechat and Q Q. The survey participants were able to respond in Chinese or English of their own choice. The responses were collected through a period of three months, May-August 2020. The free-response results were translated into English, first by Google Translate and verified by two research members, who are bilingual in Chinese and English. The free-response results were coded using a scheme adapted from open coding, as described by researchers at the University of Arizona [28]. Briefly, the responses were first read completely; then the similarities and differences between responses were analyzed, and finally preliminary categories for each response and its similarities were created.

3. Findings and discussions

3.1. Expert interview results

We interviewed seven experts in China who specialize in the field of public safety, emergency science, and public health. The identities of the interviews have been anonymized. The results of our interview coding can be seen in Fig. 1.

Many of our interviewees mentioned how important apps like Alipay and WeChat were to China’s response to COVID-19. Alipay is an online payment system similar to PayPal. WeChat runs its own online payment service nearly identical to Alipay, but it also functions as a popular instant messaging app in mainland China. Both apps store an abundance of personal information such as names, addresses, bank accounts, and user identity, which is required by Chinese law. Both apps provide platforms for in-app programs called “mini-programs.” Many COVID-19-related apps in China are on one of these two platforms.

From the interview results, we can see that the most common theme was Personal Privacy. Interviewees generally showed a lack of knowledge about how long their personal information would be held by COVID-19 apps, and they found this lack of knowledge concerning. One way this concern could possibly be addressed is by having users’ personal data automatically deleted after a certain period. According to one of the interviewees, “There is a time limit on this data...” Each city has a different limit on how long they will keep this data.” Some interviewees also expressed concerns about their privacy, although many thought that some amount of discomfort was necessary to supply these apps with important information. One interviewee said, “We’re worried but it is acceptable because health and life are our top priority at this moment, but after the COVID-19, I don’t want to connect to the health code app and other apps due to the personal information.” Other experts did not see any problems with the amount of information being collected by these COVID-19 apps. One expert spoke in favor of these apps, saying, “There’s no personal information leak in this app, since you can only know you have contact or not. ... I want to know if I have contact history that requires me to provide some personal information, (because) others also want to know if I’m sick or not, I think it’s reasonable.”

The second largest categories resulting from our coding were Government Involvement and Community Involvement. The fact that these two categories were tied for second place suggests action on the national and local level are equally important when it comes to fighting COVID-19. While the local and national government used COVID-19 apps to designate areas of need, based on risk levels, and to allocate resources to different areas, community workers and volunteers within each community used COVID-19 apps to assist them while distributing food, ensuring residents quarantined properly, and taking care of the elderly.

During the initial outbreak of COVID-19, food prices rose in several regions of China, due to a lack of preparedness on the part of the national and local governments. China’s lack of preparedness for COVID-19 extended to its use of mobile applications, which had to be rapidly developed after the outbreak of COVID-19. The precursor to China’s health code system was a railroad query system released at the beginning of the COVID-19 outbreak, which allowed railroad passengers to check if they had come into contact with any potentially infected persons. According to one interviewee, “At the beginning of the epidemic, people were frightened. As an example, I took a train during that time, so I’m not sure whether I have contacted any patient, so during that stage of time, railway system released a query system.” This query system helped China slow down the spread of COVID-19, and laid the groundwork for the health code system. After the health code system began to be used, data from the railway query system was integrated into the health code system. Many provinces, cities, communities, and school campuses used their own health code system, which caused great confusion. These apps did not share information with one another, which meant that citizens who needed to travel also needed to download and update several applications. Although this situation has gradually improved, it has not been solved, since there are still many different health code applications throughout mainland China [30] (Legal [31]). Several interviewees also expressed their concerns about the usability of these COVID-19 apps. For instance, elderly people who are not familiar with smartphones are easily confused by the need to show different health codes at different locations such as the grocery store, the gate to a community, and their places of work.

Despite the initially chaotic situation, China’s quick response to COVID-19 was effective. Initially, government agencies and communities relied on quickly constructed and prematurely released applications. As time progressed, government collaborated with third-party companies, who worked to improve the apps by updating the user interface and adding additional features.

The major takeaways from our interview analysis are as follows:

1. Applications should be cautious and transparent about how user’s private data will be stored and utilized.
2. Various COVID-19 apps should be consolidated, in order to cut down on the number of necessary apps that users have to download.
3. Apps should be developed before, and not after, disease outbreaks occur (for future preparedness).
4. Apps should take into account regional differences. Applications servicing rural areas may need to work differently from applications servicing urban areas.
5. While relatively well received, COVID-19-related apps still have room for improvement, since many people regard them as annoying. Steps should be taken to minimize the number of times users have to interact with these applications on a daily basis.
3.2. Survey results

The surveys included 16 questions, and we received 211 responses in total. It was determined by using the Sample Size Calculator at Surveysystem.com (https://www.surveysystem.com/sscalc.htm) that for 1.4 billion population, 196 responses results in a confidence level of 95% at a confidence interval of 7 and 267 responses results in a confidence level of 95% at a confidence interval of 6. The demographic information analyzed included age, gender, location, and travel history during COVID-19.

Fig. 2(a) represents the age demographics. Out of 211 responses, 117 (55%) of the respondents are between the ages of 18 to 35, 75 (36%) of the respondents are between the ages of 36 and 59, 17 (8%) are above the age of 60. According to Statista.com, it was estimated that in 2019, the 18–35 age group accounts for 41.7% of total smartphone users in China, while the 36–54 age group accounts for 38.1%, and the over-55 age group accounts for 8.1%. [5] The age demographics of the survey results is rather representative of the age demographics of smartphone users among the general population. It is obvious that younger individuals are more inclined and accustomed to using mobile technology.

Fig. 2(b) showcases the gender demographics. Out of 211 responses, 42% of the respondents reported to be male, while 57% reported to be female. Studies have shown that women are more likely to participate in surveys than men [32,33,34]. This may explain the higher number of responses by females.

The app that was used to disseminate the survey can gather location information, with the consent from participants. The 211 responses were from 25 different provinces, autonomous regions, and municipalities in China. According to Briney of ThoughtCo.com, there are 23 provinces, 4 municipalities, and 5 autonomous regions in China [35]. Three provinces, Hubei, Hunan, and Hebei contributed the largest num-

---

(6) Apps should be made easy to use and accessible to people who do not have much prior experience using mobile applications. Government agencies and community committees should allocate resources towards teaching citizens how to effectively use these apps.
number of responses, with 34, 32, and 30 responses from each province, respectively, and accounted for 45.5% of the 211 respondents. Hubei province is the province in which Wuhan, where the first case of coronavirus was reported, is located. And Hunan is one of the neighboring provinces to Hubei. Fig. 3 displays the survey responses by provinces. From this place was as Names of P Hubei province is marked with a red circle. The red color of the name of the province or municipality indicates that the number of responses from it was over 30; the purple color indicates that the number of responses was more than 10; and the green color indicates that the number of responses were fewer than 10. Adjoining provinces or municipalities are connected by black lines. Provinces not included in Figure 3 are the ones that returned no responses. Most of the responses were from the south and east of China, relatively close, geographically, to Hubei.

When asked about their travel history during the COVID-19 crisis, 82% reported no travel outside of their city. Only 16% traveled outside of their city. This result illustrates the fact that travel decreases during crises. Natalie B. Compton of the Washington Post interviewed special pathogens expert Syra Madad, for her opinion on traveling during a pandemic. Dr. Madad stated, “We’re still in the middle of the pandemic, and, unfortunately, this is something that’s going to be with us for the foreseeable future... I think no one should be traveling. All nonessential travel shouldn’t take place. If this is not something that you need to go do for your own safety, then maybe it’s something you could do at another time.” [37]. Individuals in China recognize the severity of remaining in place during a pandemic and thus didn’t travel often outside of their city. It was also interesting to note that the age group over 60 reported no travel. In the 36–59 group, 16% reported travel during the outbreak, and in the 18–35 age group, 18.8% reported travel. It seems that the younger the age group the more likely there is to be travel.

The survey also contained questions aimed at gauging the type of phone and apps every respondent used. As can be seen in Fig. 4(a), 80% of respondents used an Android phone, 12% used an iPhone, and only 7% used another device. Additionally, Fig. 4(b) shows that, while some respondents used standalone apps for COVID-19, mini-programs in the established apps like WeChat and Alipay were used the most. These two questions gave some background information on the technical context behind the responses obtained throughout the rest of the survey. The responses also indicate that it might be efficient to either alter or add onto an existing widely-used app platform. Facebook or other forms of social media may be used as the platform for hosting COVID-19 related tool in order to increase the acceptance and usage.

Answers to the survey questions suggested that most of the respondents valued the information and data that the apps provided more than information about contact tracing. Fig. 5 shows that when asked the function of each respondent’s app, 84% of them selected “Receiving health alerts” and 64% selected “Assessing information on COVID-19” (Those surveyed were allowed to select multiple options.). Additionally, when asked what they thought was the most valuable feature, 37% of the useful responses mentioned that the information provided by the app was the best part of the COVID-19 app (Fig. 6).

Data about the least valuable and most-desired missing features was also collected. However, when asked for their opinion on the least-valuable feature present in the apps, only 81 responded. Of those, 53% said that there were no useless features present in the app, as can be seen in Fig. 7. Responses in single digits suggested that in-app ads, daily body temperature reporting, video and chatting function, recommendation and advice functions, and functions irrelevant to COVID-19 were considered less valuable features. Additionally, there was a similar response to the question about any features that should be added. Only 69 of those surveyed responded to this question, and 39 out of 69 stated that they didn’t think any extra features were necessary. There were responses in single digits, suggesting the following as desirable features: local statistics; position tracing; early warning; stories in the outbreak; detailed case distribution; health and body temperature report reminders; personalized testing; and using without internet.

There were also questions designed to explore the opinions of the survey respondents towards the apps that they use. When asked if the required use of mobile apps caused inconvenience, of 148 responses received, only 18 reported inconvenience. When asked to elaborate on the cause of inconvenience, only 5 useful responses were collected, and
the following were mentioned: privacy concern, taking too much time to log in, high frequency of required log in, and too much information. When asked to rate their experience with health code apps from 1 to 5, with 1 being the worst, 5 being the best, 84% of the answers were 3 or above, indicating a good or neutral experience. The average was 3.77±1.01 (Table 2). It is interesting to note that the 18–35 age group reported average rating of 3.58, the 36–60 age group reported average rating of 3.87, and the over 60 group reported average rating of 4.85 for their experiences with the apps. The main complaints were many different health codes required, which caused confusion; the burden of a daily health report; too much personal information collected; and difficulty finding needed information. A previous study has shown that younger users are more likely to be familiar with apps, making it more probable for them to have a positive user experience with their chosen software. Older people, and those who are less familiar with technology, may have a more difficult time with the app and thus could have a correspondingly more negative experience [38]. The observation of the older age group reporting a higher satisfaction in this study is attributed
The least valuable feature of mobile apps.

**Fig. 7.** The least valuable feature of mobile apps.

| Feature                                      | Rating | Travel during COVID-19 |
|----------------------------------------------|--------|------------------------|
| None                                         | 45     | 0%                     |
| Ads                                          | 40     | 0%                     |
| Daily body temperature reporting             | 35     | 0%                     |
| Recommendations and advice                   | 30     | 0%                     |
| Video and chat                               | 25     | 0%                     |
| Everything not related to COVID-19           | 20     | 0%                     |

**Table 2**
Rating of the mobile app used.

| Age group | Average rating | Travel during COVID-19 |
|-----------|----------------|------------------------|
| 18-35     | 3.58           | 18.8%                  |
| 36-60     | 3.87           | 16%                    |
| >60       | 4.85           | 0%                     |
| Overall   | 3.77           | 16%                    |

Fig. 8. Chart of Recommendations generated by the research.

**Assist**
Assist public health officials in executing existing responses to COVID-19.

**Inform**
Provide users with useful and reliable information at the local, national, and international level.

**Protect**
Protect the information of app users, and handle user data in a responsible manner.

**Adapt**
Be able to adapt to changing cultures, geographies, and situations as a health event unfolds.

- Collect information for contact tracers
- Allow users to order provisions
- Allow users to consult with a doctor

- Provide counts on current and new cases
- Share maps showing infection risk
- Demonstrate ways to proper sanitation

- Put in place safeguards for user data
- Collect only necessary data
- Put privacy foremost

- Adapt to rural vs urban environment
- Adapt to cultural differences
- Change with the severity of the situation

to the fact that people responded to the survey are all mobile technology users, regardless of age. The older people reported less travel and thus probably did not have to navigate multiple Health Code apps. It is more likely that they only needed to become familiar with a limited numbers of apps and stayed with these. Their consistent use of familiar Health Code apps may have contributed to the reported positive experience. The data also indicates that, even though the use of mobile technology decreases with an increase in age, the acceptance of useful mobile apps by older mobile users can be as high as that of younger groups. This is an encouraging insight, since the apps are only designed for mobile users. Of course, in a holistic approach to mitigate any infectious diseases, tools that can help non-mobile users must be developed too.

It is also interesting to note that the 3 useful responses collected to the question of “Any other suggestions” all mentioned the desire of a single health-code app for nation-wide use, instead of multiple apps for each community, city and province.

4. **Recommendations**

This study generates several takeaways. The majority of respondents rated their experience suing the Health Code apps positive and stated that they primarily used their apps for getting information. Though mobile apps can certainly assist contact tracers by providing information
on symptoms, locations, and travel history, most contact tracing around the world continues to be done by trained health-care workers. For example, contact tracers in Wuhan checked in on up to 1000 citizens per day during the city-wide lockdown, meaning that while mobile applications could have assisted these workers, it did not replace them [39]. Therefore, it is recommend that mobile applications be designed to assist existing COVID-19 responses such as contact tracing, rather than replacing them.

The results also suggest that one of the primary roles of mobile applications during the current crisis should be as a platform to share accurate information on topics such as local and national infection counts, infection risks in various areas, and local and national news. This information not only helps citizens stay safe, but also helps citizens cope with the stress that comes along with health crises such as COVID-19 [40]. In addition to adding more relevant information, these apps should be streamlined in order to make it easy for users of all skill levels to access critical information and to improve the user experience. China used the already existing apps of WeChat and Alipay as platforms to host COVID-19 mini-programs. The study findings suggest that if developers wish for wide dissemination of an app, they may consider potentially adding onto an existing popular app like Facebook.

Base on this study, it is recommended that following functions to be considered in developing a mobile app for mitigating infectious diseases (Fig. 8):

- To assist existing responses to COVID-19, not replace them.
- To inform users with useful and relevant information.
- To protect users' personal information and data.
- To adapt to the location and situation of the region in which they are utilized.

Some aspects of these recommendations cannot be generalized, and they will have to be answered by each local or national government that develops the mobile apps. This study focused on user experience and suggests what should be done. The question of how remains.

We hope that future researchers will be able to use our report as a jumping-off point to develop more mobile solutions that assist citizens and public health officials around the world in the fight against COVID-19 or similar diseases. The only way to combat a global disease is with a global response, and while technology and mobile applications have a role to play, it is much more important that this response be grounded in empathy, kindness, and respect respect Fig. 8.

Declaration of Competing Interest

The authors also certify that there is no known conflict of interest to disclose.

Acknowledgements

The authors would like to thank the following: professors at WPI, Tsinghua University, and Wuhan University of Technology (WUT) for their guidance; student researchers at WUT for their invaluable assistance in translating and disseminating our survey; and all of the public safety, emergency science, and public health experts interviewed for sharing their insights and experiences.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jnlissr.2021.04.002.

References

[1] J. Gallagher, Coronavirus vaccine: when will we have one? BBC News (2020) Retrieved from https://www.bbc.com/news/health-51665497.
[2] Davidson, H. (2020). China’s coronavirus health code app raises concerns over privacy, The Guardian. Retrieved from https://www.theguardian.com/world/2020/apr/01/chinas-coronavirus-health-code-apps-raise-concerns-over-privacy
[3] N. Jao, Alipay developed china’s national health code rating system, Technode (2020) Retrieved from https://technode.com/2020/02/17/alipay-developed-chinas-national-health-code-rating-system/
[4] Silver, L. (2019, December 30). Smartphone ownership is growing rapidly around the world, but not always equally. Retrieved from https://www.pewresearch.org/global/2019/02/05/smartphone-ownership-is-growing-rapidly-around-the-world-but-not-always-equally/
[5] Statista. (2020). Number of mobile internet users in China from 2015 to 2019 with a forecast until 2023. https://www.statista.com/statistics/558731/ number-of-mobile-internet-user-in-china/
[6] Statista. (2020). Distribution of smartphone users in China from 2013 to 2019, by age group. https://www.statista.com/statistics/224116/smartphone-users-in-china-by-age/.
[7] Utopia, Alipay & WeChat pay: all you need to know about smart payment in China, Utopia (2020) Retrieved from https://utopiamag.com/en/2020/01/30/ alipay-ipay-all-you-need-to-know-about-smart-payment-china/.
[8] A. Kharpal, Everything you need to know about WeChat · China’s billion-user messaging App, CNBC (2020) Retrieved from https://www.cnbc.com/2019/ 02/04/what-is-wechat-china-biggest-messaging-app.html#:~:text=WeChat%20is%20China%27s%20largest%messaging%20app%20with%20have%20used %20billion%20users%20outside%20China.
[9] D. Roberts, Alibaba Spinnoff Alipay Surpassed 1 Billion Users in 2019, Yahoo Finance, 2020 Retrieved from https://finance.yahoo.com/news/alibaba- spinnoff-alipay-surpassed-1-billion-users-2019-050700339.html
[10] K. Warner, China takes steps to become first cashless society after COVID-19, The National (2020) Retrieved from https://www.thenational.ae/china/ americas-steps-to-become-first-cashless-society-after-covid-19-1.1011042
[11] S. Standing, C. Standing, Mobile technology and healthcare: the adoption issues and systematic problems, Int. J. Electronic Healthcare 4 (2008) 2-
[12] R. Braun, C. Catalani, J. Wimbush, D. Israelski, Community health workers and mobile technology: a systematic review of the literature, PLoS ONE 8 (6) (2013) e65772.
[13] N. Mahmood, J. Rodriguez, J. Nesbitt, A text message-based intervention to bridge the healthcare communication gap in the rural developing world, Technol. Health Care 18 (2) (2010) 137–144.
[14] A. Chib, M.O. Lwin, J. Ang, H. Lin, F. Santoso, Midwives and mobiles: using ICTs to improve healthcare in Aceh Besar, Indonesia, Asian J. Commun. 18 (4) (2008) 348–364.
[15] Liz Burley, Helena Schepers, Julie Fisher, Diffusion of mobile technology in health care, in: Proceedings of the Euro MGOV 2005 First European Mobile Government Conference, 2005.
[16] J. Li, Applications of E-health for pandemic management, 12th IEEE Conference on e-Health Networking, Application, and Services, 2010.
[17] S.D. Young, A “Big Data” approach to HIV epidemiology and prevention, Prevent. Med. 70 (2014) 17–18.
[18] E. Aramaki, S. Maskawa, M. Morita, Twitter catches the flu: detecting influenza epidemics using Twitter, in: Proceedings of the Conference on Empirical Methods in Natural Language Processing (EMNLP ’11), Association for Computational Linguistics, 2011.
[19] C.M. Astley, L. Danon, S.P. Dowell, M. Lajous, J.J. O’Hagan, Mobile messaging as surveillance tool during pandemic (H1N1) 2009, Mexico, Emerg. Infect. Dis. 16 (2010) 9.
[20] A. Barrionuevo, Coronavirus tracking apps are being tested around the world, but will concerts get on board? Billboard (2020) Retrieved from https://www. billboard.com/articles/news/international/9391534/coronavirus-tracing-apps-concerts-tech-privacy-concerns.
[21] J. Khan, Digital Contact Tracing For Pandemic Response, Johns Hopkins University Press, Baltimore, Maryland, 2020.
[22] O. Holmes, J. McCurry, M. Safi, Coronavirus mass surveillance could be here to stay, experts say, The Guardian (2020) Retrieved from https://www.theguardian.com/world/2020/jun/18/coronavirus-mass-surveillance-could-be-here-to-stay-tracking.
[23] S. Bond, Apple, google in conflict with states over contact-tracing Tech. NPR (2020).
[24] M. Kim, Seoul’s radical experiment in digital contact tracing, The New Yorker (2020) Retrieved from https://www.newyorker.com/news/newsdesk/ seoul-radical-experiment-in-digital-contact-tracing.
[25] Office of the Governor, North Dakota Launches Care19 App to Combat COVID-19, North Dakota Office of the Governor (2020) Retrieved from https://www.governor.nd.gov/news/north-dakota-launches-care19-app-combat-covid-19.
[26] L. Tam, Why privacy is an alien concept in Chinese culture, South China Morn. Post (2018) Retrieved from https://www=scmp.com/news/hong-kong/article/2139946/why-privacy-alien-concept-china-and-healthcare
[27] Adler, L. (2015). Give Candidates interview questions in advance to increase accuracy. LinkedIn Talent Blog., Retrieved from https://business.linkedin.com/talent-solutions/blog/2015/02/give-candidates-interview-questions-in-advance-to-increase-accuracy.
[28] E. Blair, A reflexive exploration of two qualitative data coding techniques, J. Methods Meas. Soc. Sci. 6 (1) (2015) 14–29 doi/[https://doi.org/10.2456/v61.18772.
[29] Quinn, P. (n.d.). Survey Design: A Mini-Guide to Some Best Practices. Quinn Evaluation Consulting.
[30] China Daily. (2020). One code for all: all provinces are working on make the apps into one [Chinese]. Cybersecurity Admin. China. Retrieved from: http://www.cac.gov.cn/2020-04/14/c_1588409502738547.htm.
[31] Legal Daily, Many provinces achieved code cross reference. Professionals warned: keep your information safe [Chinese], Xinhua News Agency. Retrieved from (2020) http://www.xinhuanet.com/politics/2020-03/18/c_1125727318.htm.

[32] R. Curtin, S. Presser, E. Singer, The effects of response rate changes on the index of consumer sentiment, Public Opin. Q. 64 (2000) 413–428.

[33] D.L. Moore, J. Tarnai, Evaluating nonresponse error in mail surveys, in: R.M. Groves, D.A. Dillman, J.L. Eltinge, R.J.A. Little (Eds.), Survey Nonresponse, John Wiley & Sons, New York, 2002, pp. 197–211.

[34] E. Singer, J. van Hoevyyk, M.P. Maher, Experiments with incentives in telephone surveys, Public Opin. Q. 64 (2000) 171–188.

[35] Briney, A. (2020, February 11). Discover the 23 provinces of China. Retrieved from https://www.thoughtco.com/china-provinces-4158617

[36] Travel China Guide. (2020). Map of China provinces and cities. Travel China Guide. Retrieved from https://www.travelchinaguide.com/map/china_map.htm

[37] Compton, N. (2020). Here’s what experts want you to know before taking a road trip during the pandemic. Retrieved from https://www.washingtonpost.com/travel/tips/heres-what-experts-want-you-know-before-taking-road-trip-during-pandemic/

[38] A Smith, Older adults and technology use, Pew Rese. Center: Internet, Sci. Tech., Pew Res. Center (2020) 30 May www.pewresearch.org/internet/2014/04/03/older-adults-and-technology-use/.

[39] CGTN Youtube, The lockdown: one month in Wuhan, CGTN (2020) Retrieved from https://www.youtube.com/watch?time_continue=98&v=xU9FVqwO4TM&feature=emb_logo.

[40] J. Hilotn, Life Under Lockdown in Wuhan: They Dance, Chant as Hope Springs Eternal Under Coronavirus Watch. Gulf News, Sing, Run, 2020 Retrieved from https://gulfnews.com/world/asia/life-under-lockdown-in-wuhan-they-dance-sing-run-chant-as-hope-springs-eternal-under-coronavirus-watch-1.1581930123869.