EMPIRICAL ARTICLE

Resolving the tension between full utilization of contact tracing app services and user stress as an effort to control the COVID-19 pandemic

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Abstract

Although contact tracing apps can be effective for controlling COVID-19, the app usage can be stressful for users. This study identifies countermeasures for users' stress while maximizing full utilization of the apps. This study presents the relationships among the stress factors, users' appraisal, users' emotion focus coping, and the infusion to exert the full potential of the app through a structural equation model. The research model is validated by surveying Health Code app users. Given the results of the study, the contact tracing apps could become a valuable tool to control COVID-19 by removing app users' privacy concerns.

Keywords COVID-19 · Contact tracing · Privacy concern · Accuracy concern · Coping theory · Pandemic

1 Introduction

Overcoming coronavirus disease 2019 (COVID-19) is the largest pending global issue. Despite worldwide efforts, there currently is no specific vaccine against COVID-19 (CDC 2020). Meanwhile, health authorities are suggesting preventative measures such as tracing and isolating early-stage confirmed COVID-19 patients and those who contacted the patients, along with social distancing, mask wearing, and hand washing (UN 2020). Authorities around the world are temporally permitting implementations of digital contact tracing apps on smartphones to find confirmed cases and trace their travel logs (Kelion 2020; Servick 2020).

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A recent research showed the effectiveness of the digital contact tracing apps for epidemic control using mathematical simulations (Ferretti et al. 2020). The simulation based on a mathematical model proposed by Ferretti et al. (2020) provides evidence that digital contract tracing apps could stop the COVID-19 epidemic by using the reproductive number, R0 = 2.0 calculated from data collected from the early COVID-19 stages in China. Some of the successful examples of contact tracing apps in usage are *Self-quarantine Safety Protection App* required for South Korean residents by its government and *Health QR Code Apps* (hereafter called Health Code) mandated by the Chinese government (CDSCHQ 2020a; Gan and Culver 2020). There are two types of contact tracing technologies: a centralized system and a distributed system (Ferretti et al. 2020; Servick 2020). The centralized system stores all contact tracing information on a central server using the global positioning system (GPS) to trace travel logs of smartphone users (Servick 2020). The distributed system uses Bluetooth Low Energy (BLE) technology to trace travel information and store data in individuals' smartphones (Ferretti et al. 2020; Servick 2020). In the centralized system, collected data include information on when, where, and with whom an individual met, what the individual bought, and the activities the individual conducted. Thus, while the centralized system is efficient as the quarantine authority can integrate and manage all relevant data, users are concerned about authority's invasive surveillance powers (Gallagher 2020). In other words, while users do understand that contact tracing apps are needed during the pandemic, they also exhibit increased stress and anxiety over security issues related to their personal information (Mozur et al. 2020).

In general, technology users feel more stressed under mandatory settings of technology acceptance than from voluntary acceptance (Marakhimov and Joo 2017). Despite users' stress, the mandatory acceptance of contact tracing apps results in greater effectiveness of reducing the spread of COVID-19 than voluntary acceptance. Thus, for being required by both governments, Self-quarantine Safety Protection app of South Korea and Health Code app of China are representative technology for examining the relationship between the effectiveness of mandatory centralized contract tracing apps and user stress. Technology related stress (called technostress) results in a negative emotional state and a severe state of anxiety (La Paglia et al. 2008). Coping theory refers to a process of conscious and unconscious efforts to overcome stress (Lazarus and Folkman 1984). It is necessary to examining the tension between the diffusion of contact tracing apps and user stress by applying coping theory.

To exert full potential of contact tracing technology to control the spread of COVID-19, it is critical to resolve the tension between benefits of the contact tracing apps and users' stress. Moreover, it is necessary to find the causes of contact tracing app user stress which restricts the utility of the app. First, this study aims to examine users' accuracy concerns arising from potential problems of using contact tracing apps and privacy concerns from privacy infringement as the potential causes of user stress. Based on the coping theory (Beaudry and Pinsonneault 2005; Lazarus and Folkman 1984), this study proposes a structural equation model that shows the relationships between contact tracing app users' stress and how they accept such stress through a process called challenge appraisal. Once users appraise the stress as an

opportunity they emotionally cope with the stress and they may engage in the infusion behavior of using the contact tracing app to its fullest potential (Jones et al. 2002). To test the research hypotheses derived from the proposed structural equation model, survey data were collected from the users of Health Code, which is the mandatory and centralized contact tracing app with the largest user base.

Contact tracing apps can be used for a variety of purposes even when the vaccine for COVID-19 is developed. Vaccines as a means of disease prevention have limitations that new vaccines should be developed when a new infectious disease emerges, and their development takes a long time. However, the contact tracing apps have the advantage that they can be applied quickly without major modification even for new infectious diseases. Since this study can shed insight on maximum benefits of the contact tracing apps while protecting individual privacy, it can contribute to preventing the spread of new infectious diseases including COVID-19.

2 COVID-19 contact tracing apps and theoretical background

2.1 COVID-19 contact tracing app service

South Korea is one of the few countries that are successfully dealing with COVID-19. As shown in Table 1, diverse information communication technologies (ICTs) have been applied to prevent the spread of COVID-19 in South Korea. ICTs such as artificial intelligence and big data are applied to the support for the treatment of COVID-19. The COVID-19 Epidemiological Investigation Support System (EISS) combined with physical interviews plays a great role in tracking confirmed cases and contacts of COVID-19 (The Government of the Republic of Korea 2020). This system identifies the travel logs of only those patients who have been determined as confirmed cases by the Korea Centers for Disease Control (KCDC) on the map and supports quick responses to COVID-19 control teams using the relevant statistical information (Park et al. 2020). The EISS integrates data in conjunction with the smart city data hub, which collects and processes data from large cities, developed by the Ministry of Land, Infrastructure and Transport. The EISS analyzes data including location information and credit card usage details of confirmed cases, in real time using with the support diverse statistical methods to automatically identify travel logs and points-of-stay by time zones, and provides routes of infection and hot spots to identify the source of infection in each area (Park et al. 2020). By using the EISS, the travel routes of confirmed cases can be identified and analyzed within ten minutes (The Government of the Republic of Korea 2020).

Contact tracing is critical in epidemiological investigation (The Government of the Republic of Korea 2020). Identification of those who have been in contact with a confirmed case in early stages plays an important role in preventing the spread of COVID-19 (Park et al. 2020). Therefore, many countries have adopted mitigation and suppression strategies that trace the travel routes of confirmed cases to identify and isolate contacts, thereby reducing the overall scale of incidence (Walker et al. 2020). Diverse apps for digital contact tracing have been developed and used in various countries (Kelion 2020; Servick 2020). Successful examples include

Table 1 ICT applications for controlling COVID-19

Applications	Cases
ICTs for social distancing	SMS text messaging system: A service that notifies confirmed cases' travel routes with text messages
	Smart working: (Video) teleconference, utilization of Global Virtual Private Network (GVPN) & G-Drive (cloud storage) for flexible telework, interlocking with intranet
	Distance education: Support for education using AR/VR
	Temporary Remote Medicare Service: COVID-19 confirmed case treatment and remote prescription using apps
	COVID-19 Confirmed Case and Movement Map App: A service that notifies app users of the travel routes of the confirmed cases provided by the KCDC
	COVID-19 Contact Risk Calculation App (app Now and Here): An application that calculates the likelihood of danger by comparing travel routes of app users with those of nearby confirmed cases
	An application that notifies when the user visits the travel routes of confirmed cases (app Cobaek): An application that provides the warning message when the user is within 100 m of a place visited by a confirmed case and informs users of nearby pharmacies with public mask inventory
ICTs for prompt diagnosis	ICT-based COVID-19 diagnostic kit
	Artificial intelligence-based confirmed case examination
ICTs for contact tracing	Self-diagnosis app: An application that supports the self-diagnosis of entrants from overseas countries with fever, cough, sore throat, and breathing difficulties, etc.
	Self-quarantine safety protection app: An application for persons in self-quarantine to enter their health condition twice a day, and for notification of breakaway from the quarantine area
	An app for self-quarantine managers and for notification of breakaway: An application for management of persons in self-quarantine and for notification of breakaway from the designated place
	Epidemiological Investigation Support System: KCDC's confirmed cases' travel route tracking system linked with Smart City's data server

Source The Government of the Republic of Korea (2020)

Self-quarantine Safety Protection app (South Korea) and Health Code app (China), both of which are based on the centralized system (CDSCHQ 2020a; Gan and Culver 2020).

The South Korean Self-quarantine Safety Protection app offers services such as self-diagnosis of the health conditions of individuals in self-quarantine, guidance for living rules, and emergency contact networks to effectively control individuals in self-quarantine (CDSCHQ 2020a). Individuals in self-quarantine are required to

self-report their health conditions, such as fever, cough, sore throat, and dyspnea symptoms and the report results are automatically sent to the KCDC twice a day. In addition, the location information of individuals in self-quarantine is automatically reported to the KCDC in real time. When the individual leaves his/her designated quarantine location, an alarm notification is sent to both the quarantined individual and the KCDC. Then, the KCDC official who is responsible for the location immediately takes necessary actions (CDSCHQ 2020a; The Government of the Republic of Korea 2020).

Health Code is a contact tracing app with the largest user base in China since early February 2020 (Mozur et al. 2020). The app displays a green, yellow, or red QR code according to each user's health status thereby acting as a pass permit. Users with a green code are allowed to visit others, but those with a yellow code should undergo self-quarantine for 7 days, and those with a red code must self-isolate for 14 days.

For digital contact tracing, South Korea uses mobile phone location tracking (location information at the communication base station), credit card usage details, and CCTV records (CDSCHQ 2020a). China uses mobile phone location tracking, facial recognition, CCTV, drones, and QR codes (Gan and Culver 2020). Users of these contact tracing apps report significant stress over the invasive surveillance functions that they are required to abide by (Davidson 2020; Mozur et al. 2020).

2.2 Coping theory

Coping theory explains individuals' conscious or unconscious endeavors to solve problems and reduce stress. Lazarus and Folkman (1984, p. 141) defined coping as "constantly changing cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the resources of the person." In other words, it is the process of actively adapting to events that are happening and may happen in the future. Coping theory has been applied in the fields of psychology, sociology, medicine, and social welfare. Coping theory is also used in ICT research. Beaudry and Pinsonneault (2005) proposed the Coping Model of User Adaptation (CMUA), which is a model describing users' adaptation to ICTs based on coping theory. CMUA includes the process that users experience when using a new ICT, which consists of awareness, appraisal, adaptation, and outcome (Beaudry and Pinsonneault 2005).

While contact tracing apps can be an effective COVID-19 control system, the app as a new ICT is causing users stress because they must unwillingly adapt and accept the novel invasive surveillant technology. The European Parliament (EP) insists on preventing the abuse of personal information by legislating that it is not stored in a central database, and applying sunset clauses. The EP recommends that personal information is deleted as soon as COVID-19 is no longer a threat, and a decentralized system applying BLE technology (EP 2020). In the cases of South Korea and China, user stress may be higher than in Europe since these two countries have adopted the centralized system for their contact tracing apps.

2.3 Infusion

In the technological diffusion approach, new ICTs become standard means by which individuals or organizations undertake the processes of initiation, adoption, adaptation, acceptance, routinization, and infusion (Cooper and Zumd 1990; Jones et al. 2002; Zmud and Apple 1992). From an organizational perspective, Zmud and Apple (1992) defined infusion as "the extent to which the full potential of the innovation has been embedded within an organization's operational or managerial work systems." Jones et al. (2002) defined infusion at the individual level as "the extent to which a person uses technology to its fullest extent to enhance his or her productivity." In other words, infusion is the process through which technology is accepted by individuals or organizations and used so that its full potential functions are realized.

Contact tracing apps such as Self-quarantine Safety Protection app and Health Code app are actually initiated and accepted by users in mandatory settings for controlling COVID-19 pandemic. However, the process of adaptation to infusion partially depends on users' emotion and ability because a variety of factors such as their stress and attitude affect adaptive efforts.

3 Research model and hypotheses

3.1 Concerns about contact tracing apps and challenge appraisal

Mason (1986) categorized ethical issues of information age and among them are (1) accuracy and (2) privacy. Accuracy is associated with the authenticity, fidelity, and precision of the information (Mason 1986). Privacy asks the fundamental question of where the borderline is between the information that should or should not be shared with others (Mason 1986). Concerns about inaccuracy and privacy infringement are raised with regards to contact tracing apps to control the spread of COVID-19 (Davidson 2020; Mozur et al. 2020). Health Code users in China reported concerns about the lack of transparency related to the app's operations, scope of data storage, inability to change an erroneous "red" code, excessive dependence on the Internet, and reliance on private companies such as Alipay and WeChat monitoring their travel routes (Davidson 2020; Mozur et al. 2020). As previously reviewed, users of contact tracing apps may experience stress mainly due to concerns over the following two issues: being mistakenly subjected to self-quarantine due to incorrect data input or technical errors in the contact tracing app; privacy infringement due to the system storing their personal information in the centralized system. In this context, this study proposes accuracy and privacy concerns as the main causes of user stress for contact tracing apps.

Users who perceive stress when using contact tracing the apps appraise each stressful situation as a threat or challenge (Fadel and Brown 2010; Lazarus and Folkman 1984). Based on the above discussion on concerns and challenge appraisal, this study proposes the following hypotheses:

Hypothesis 1 Accuracy concerns about contact tracing apps affect the challenge appraisal.

Hypothesis 2 Privacy concerns about contact tracing apps affect the challenge appraisal.

3.2 Emotion-focused coping behavior

In the appraisal stage of contact tracing apps, users assess whether contact tracing apps are an opportunity to prevent the spread of COVID-19 or a threat to their individual liberty. In the cases of the Self-quarantine Safety Protection app in South Korea and Health Code app in China, users cannot refuse their use since they are mandatory. Thus, users try to appraise the perceived consequences of the apps as a new opportunity and then undertake adaptation efforts to satisfy these expected benefits, which were termed as emotion-focused behaviors by Beaudry and Pinsonneault (2005).

Fadel (2012b) conducted an empirical study using a survey of electronic medical systems at university health departments to validate the CMCA (Beaudry and Pinsonneault, 2005). According to Fadel (2012b)'s study, appraisal of electronic medical systems as a challenge resulted in increased engagement in adaptation behaviors. In the similar sense, Marakhimov and Joo (2017) reported positive relationship between users' challenge appraisal of wearable devices and their emotion-focused coping behaviors toward the wearable devices (Marakhimov and Joo 2017). Moreover, according to a study by Joo (2019) regarding infusion of smart grid technology, challenge appraisal of technology significantly influences positive reappraisal. Positive reappraisal as a kind of emotion-focused coping behavior refers to efforts to create or ascribe positive meaning to the technology. Thus, the present study posits the following hypothesis:

Hypothesis 3 Challenge appraisal of contact tracing apps affects the emotion-focused coping behavior.

3.3 Infusion

There have been a few studies on the relationship between emotion-focused coping behaviors and infusion of information systems. In the individual level, emotion-focused coping behaviors positively influence work efficiency and effectiveness (Beaudry and Pinsonneault 2005). Emotion-focused coping behaviors are significantly associate with infusion of information systems at the individual level (Fadel 2012a). Joo (2019) reported that users of smart grid technology achieved the fullest potential of the smart system by utilizing positive reappraisal based on emotion-focused coping behaviors. Thus, the following hypothesis is proposed:

Hypothesis 4 Emotion-focused coping behavior toward contact tracing apps affects user infusion.

Figure 1 shows the relationships among accuracy and privacy concerns as factors affecting stress, challenge appraisal, emotion-focused coping behavior, and infusion as a structural equations model. An individual that feels stress due to concerns about contact tracing apps appraise the stressful situation (Fadel and Brown 2010; Lazarus and Folkman 1984). When users experience a new IT service, the new features constitute a challenge that they must evaluate (Fadel and Brown 2010). During challenge appraisal, users of apps undertake emotion-focused coping behavior in an attempt to identify positives and strengths or to avoid/tolerate negative aspects or risks. Through emotion-focused coping behavior, users of contact tracing apps adapt to attain the full potential benefits of the app. The research model in Fig. 1 is based on the stress-coping-adaptation model of Lazarus and Folkman (1984), CMUA of Beaudry and Pinsonneault (2005), and stress-coping model of Joo (2019).

4 Methodology and analysis

4.1 Measurement and sample design

Table 2 shows measurement items for the five constructs in the proposed research model. The measurement items were modified and adopted from the studies conducted by Fadel (2012b), Marakhimov and Joo (2017), and Joo (2019) to fit the purpose of the current study. Each of the 15 questions for the five constructs was measured on a five-point Likert scale. The questionnaire was developed in Korean, and three graduate students who were bilingual in Korean and Chinese translated the questionnaire into Chinese and mutually reviewed the translations. Finally, editing of the translation was commissioned to an agency specializing in Korean and Chinese. The survey was conducted targeting Health Code app users in China.

Although both Self-quarantine Safety Protection app of South Korea and Health Code app of China are good samples of centralized contact tracing apps, Korean sample is inefficient for the data collection purpose of the research. As KCDC requires those who are infected or had contacted the infected to install Self-quarantine Safety Protection app, only KCDC has the full list of those who have installed the app. However, Health Code of China is required for all its residents regardless
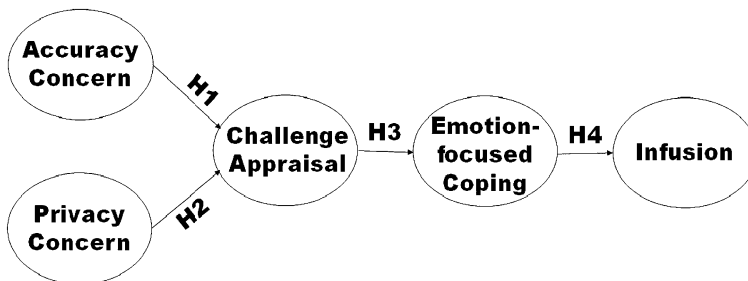

Fig. 1 Research model

Table 2 Measurement items

Construct	Operational definition	Question items	Sources
Accuracy concern	The degree of concern about the possibility of errors in data input or unintended data usage on the contact tracing app	I am concerned about getting red or yellow code by mistakenly inputting health status in the *Health Code* (*Health QR code*) *App*	Developed
		I am concerned about getting red or yellow code due to operational error by the *Health Code App* service provider	
		I am concerned about being penalized for wrongful data entry even though I enter accurate health status in the *Health Code App*	
Privacy concern	The degree of concern about the possibility of abuse of personal information of contact tracing app users and consequential risks	I am concerned about the possibility of my health status information entered in the *Health Code App* to be used for other purposes	Developed
		I am concerned about the possibility of any risks due to the exposure of my health status information through the *Health Code App*	
		I am concerned about being monitored by using the *Health Code App*	
Challenge appraisal	The degree of evaluating positive aspects of contact tracing app as a challenging opportunity	I believe that using the *Health Code App* will help prevent the spread of COVID-19	Fadel (2012b), Fadel and Brown (2010), Joo (2019)
		I believe that using the *Health Code App* will help keep our communities healthy	
		I believe using the *Health Code App* will help end COVID-19 faster	

Table 2 (continued)

Construct	Operational definition	Question items	Sources
Emotion-focused coping behavior	The degree of voluntary effort to highlight the strengths and benefits rather than negative aspects of the contact tracing app	I try to place emphasis on the advantages of the *Health Code App* I make efforts to do my part for the *Health Code App* to reach its full potential I regarded the *Health Code App* as a bit negatively at first, but I gradually try to see the positive aspects of it	Fadel (2012a), Joo (2019)
Infusion	The degree to which users sufficiently utilize the potential benefits of the contact tracing app and are willing to recommend the app to others	I, now, understand the benefits of the *Health Code App* and sufficiently utilize the app I will use the *Health Code App* hereafter when necessary I will proactively recommend using the *Health Code* to others around me	Fadel (2012a), Jones et al. (2002), Joo (2019)

of their current infection status. Thus, data regarding user behaviors on mandatory centralized contact tracing apps can effectively be collected from general Chinese population and is most likely the only available national user data on the app. Based on the data, it is possible to generalize user behaviors toward mandatory and centralized contact tracing apps in other countries, including South Korea.

In order to reach respondents with experiences using the app, the current study employed snowball sampling using WeChat. Excluding missing data, error responses, and inadequate answers, a total of 280 valid responses were used for the analyses.

4.2 Characteristics of samples

Characteristics of the samples are organized in Table 3. Male respondents outnumbered female respondents, as the percentage of male respondents was 63%. The proportion of respondents in their 20s and 30s was high at 41%, and 58% of respondents have been using the Health Code more than two months. Alipay's app was shown to be the most widely used, followed by WeChat and local government apps in order of precedence.

4.3 Validity and hypothesis testing

The reliability, validity, and research hypothesis of the research model were tested using Smart PLS (version 3.3.2). Common method bias (CMB) may occur in cases where independent and dependent variables are measured in the same way during data collection (Kock 2015). Harman single factor tests and Variance Inflation

Table 3 Demographic characteristics ($N=280$)

Variable	Categories	Frequency	Percent
Gender	Male	176	62.9
	Female	104	37.1
Age	Under 20	52	18.6
	20–29	62	22.1
	30–39	57	20.4
	40–49	46	16.4
	50–59	44	15.7
	Over 60	19	6.8
Job experience	Under 1 month	37	13.2
	1–2 months	82	29.3
	2–3 months	85	30.4
	Over 3 months	76	27.1
Type of Health QR Code App	Alipay	104	37.1
	WeChat	87	31.1
	Local government	73	26.1
	Others	16	5.7

Table 4 Cronbach's alpha

Construct	No. of items	Cronbach's alpha	SD	t	p
Accuracy concern (AC)	3	0.738	0.029	15.677	0.000
Privacy concern (PC)	3	0.738	0.029	25.333	0.000
Challenge appraisal (CA)	3	0.635	0.045	13.974	0.000
Emotion-focused coping behavior (EC)	3	0.642	0.042	15.191	0.000
Infusion (IN)	3	0.705	0.034	20.591	0.000

Table 5 Convergent and discriminant validity

	CR	AVE	AC	PC	CA	EC	IN
UC	0.835	0.633	(0.795)				
PC	0.843	0.643	0.504	(0.802)			
CA	0.804	0.578	0.028	− 0.170	(0.760)		
EA	0.807	0.587	0.071	− 0.113	0.565	(0.766)	
IN	0.836	0.629	0.038	− 0.147	0.496	0.632	(0.793)

CR Composite reliability, *AVE* average variance explained, *AC* accuracy concern, *PC* privacy concern, *CA* challenge appraisal, *EC* emotion-focused coping behavior, *IN* infusion. Inter-construct correlations, numbers in () on the diagonal line are the square root of AVE for each construct

Factor (VIF) were used to check CMB. In the exploratory factor analysis of the Harman single factor test, it is unlikely that CMB is present when the total variance of the unrotated first factor is less than 50% (Podsakoff et al. 2003). In the case of this study, since the total variance of the first factor was 21.19%, CMB was determined as being unlikely. In a structural equation model, CMB may exist when the VIF of a potential variable is 3.3 or higher (Kock 2015). In the present structural equation model, VIFs of all potential variables were found to be between 1.000 and 1.340, which demonstrates that the possibility of CMB is very low.

Cronbach's alpha, an indicator of internal consistency of variables, was below the standard of 0.7 (Hair et al. 2017) in the challenge appraisal and emotion-focused coping behavior but was found to be reliable at a significance level of 0.001 as a result of 1000 instances of bootstrapping. Therefore, there is no conflict regarding the reliability of the variables from the perspective of internal consistency (Table 4).

Composite reliability (CR) and average variance extracted (AVE) are used for the evaluation of convergent validity. As shown in Table 5, the CR values of all variables at least satisfied the reference value of 0.7 and the AVE values exceeded the reference value of 0.5 (Fornell and Larcker 1981). Therefore, each variable in this research model shows convergent validity. Variables have discriminant validity when the square root of AVE is greater than the correlation coefficients of the relevant variables (Fornell and Larcker 1981). In Table 5, the value of the diagonal column is the square root of the AVE, and since it is larger than the correlation coefficients of the individual variables, the variables have discriminant validity.

Table 6 Hypothesis test results

Hypothesis	Path	VIF	Path coefficient	Standard deviation	t	p	Result
H1	AC→CA	1.340	0.152	0.117	1.303	0.193	No supported
H2	PC→CA	1.340	− 0.247	0.072	3.420	0.001	Supported
H3	CA→EC	1.000	0.565	0.047	12.023	0.000	Supported
H4	EC→IN	1.000	0.632	0.047	13.315	0.000	Supported

Table 7 Path analyses: specific indirect effects

Path	Indirect effect	Standard deviation	t	p
AC→CA→EC→IN	0.054	0.043	1.254	0.210
PC→CA→EC→IN	− 0.088	0.029	3.086	0.002
CA→EC→IN	0.357	0.044	8.078	0.000

In general, there is no multicollinearity, which explains correlations between independent variables, when the VIF is below the reference value of 5.0 (Hair et al. 2017). Since all VIFs were found to be are 0.134 or less, as shown in Table 6, multicollinearity is unlikely to exist.

The standardized root mean square residual (SRMR) is used for the goodness-of-fit of the structural equations model using PLS (Garson 2016). The goodness-of-fit is regarded to be high when the SRMR is not greater than the reference value of 0.08 (Hu and Bentler 1999). The SRMR of this research model was shown to be 0.084, which is not too beyond the standard.

Path coefficients are used to test research hypotheses using SmartPLS. Table 6 shows the results of test of the research hypotheses. The hypothesis (H1) that accuracy concern for the contact tracing app affects the challenge appraisal was not supported. The hypothesis (H2) that privacy concern affects the challenge appraisal was supported at a significance level of 0.01. The two hypotheses (H3 and H4) that challenge appraisal affects emotional coping behavior and that emotion-focused coping behavior affects infusion were supported at a significance level of 0.001, respectively.

Table 7 shows the results of the path analysis. The path for challenge appraisal, emotion-focused coping behavior, and infusion (CA→EC→IN) demonstrates the significant impact of challenge appraisal on infusion. On the other hand, the path for privacy concern, challenge appraisal, emotion-focused coping behavior, and infusion (PC→CA→EC→IN) shows the significant negative impact of privacy concern on infusion. Eventually, if concerns about privacy infringement are resolved, app users can more actively engage with apps and maximize their potential benefits through emotion-focused coping behavior (Table 8).

The R-squared values of emotion-focused coping behavior (EC) and infusion (IN) were shown to be satisfactory at 0.317 and 0.398, respectively (Garson

Table 8 R-square

	R-square	t-value	p-value
EC	0.317	5.936	0.000
IN	0.398	6.635	0.000

2016). In particular, the emotion-focused coping behavior of users of contact tracing apps accounted for 39.8% of the infusion.

5 Conclusion

5.1 Discussion

According to the results of the current study conducted on mandatory centralized contact tracing app users, accuracy concerns about the apps did not significantly affect challenge appraisal. On the other hand, concerns about privacy infringement by contact tracing apps had significant negative effects on challenge appraisal. In addition, challenge appraisal had positive effects on emotion-focused coping behavior, through which app users effectively transitioned to the stage of infusion to maximize the potential benefits of the app.

With regard to research hypothesis H3, users who appraise contact tracing apps in terms of a challenges more actively conducted emotion-focused coping behavior when using the app. That is, users who appraise contact tracing app as providing a new opportunity to prevent and end the spread of COVID-19 showed efforts to highlight and magnify the strengths and benefits. Regarding to research hypothesis H4, users attempted to enhance the app's strengths and benefits through emotion-focused coping behaviors, even if they recognized negative aspects in the early stages of use. In a study conducted by Marakhimov and Joo (2017) on users of wearable devices for healthcare, challenge appraisal was shown to positively affect the extended usage of the wearable devices through emotion-focused coping behavior. In a study conducted by Joo (2019) on users of smart grid technologies, the more that users engaged in challenge appraisal of the technology, the more that they conducted emotion-focused coping behavior to actively maximize the potential of smart grid technologies. These studies support the results of the current study on the significant relationships among challenge appraisal, emotion-focused coping behavior, and infusion.

With regard to research hypothesis H2, the more concerned users are about privacy infringement with regard to the contact tracing app, the less users conduct challenge appraisal of the app. Therefore, reducing concerns about privacy infringement may help users to reframe issues related to the app as instead challenges to overcome as well as recognize the strengths and benefits of the app. A previous study also reported that users' concerns about inputting personal health information into the wearable devices had a negative impact on users' challenge appraisal of the devises (Marakhimov and Joo 2017).

With regard to research hypothesis H1, concerns about problems related to inaccuracy, such as input errors or incorrect results, did not significantly affect app users' challenge appraisal. The reason why research hypothesis H1 was not supported is related to the sociopolitical and cultural systems of China. Although private companies and local governments provide Health Code services, in reality, the central government forces people to mandatorily install and use the app. Users of Health Code apps have a strong belief that they should trust and conform to government orders during these extraordinary circumstances of the pandemic. In such crisis, users tend not to think about errors in data operations or even be skeptical about the possibility of wrongful government operations. In addition, an online discussion was conducted with five graduate students in China who responded to the questionnaire in order to determine why research hypothesis H1 was not supported. Three out of the five students argued that accuracy concerns about incorrect or wrongful information usage did not affect their challenge appraisal of the apps, and they further stated that the reason is that most Chinese people trust app services in which the government is involved.

Given the results of the path analysis, relieving concerns about privacy infringement regarding the use of apps will enable users to realize the full potential benefits of contact tracing apps and make a greater contribution to preventing the spread of COVID-19. Therefore, if the distributed system is used for contract tracing apps rather than the current centralized system, more effective COVID-19 control can be expected. In collaboration with each other, Google and Apple have decided to provide Bluetooth-based distributed contact tracing technology to all quarantine authorities (Dumbrava 2020; Apple 2020). Quarantine authorities in each country will be able to use these open APIs (application programming interfaces) to develop customized contact tracing apps to reduce the concerns about privacy infringement to some extent. However, even for the distributed system, users' active participation and trust in operating authorities are paramount. In cases in which the centralized contact tracing system is used, it is necessary to be transparent and disclose how personal information will be safely and expediently deleted when the treat of COVID-19 is over.

South Korea also decided to introduce an electronic entry and exit registration (QR code) system (called Korea Internet-Pass) for facilities at risk of mass infection from June 2020 (CDSCHQ 2020b). Users who visit designated facilities must present a personalized encrypted one-time QR code to the facility manager. The facility manager then scans the user's QR code and automatically transmits it to the Social Security Information Service (SSIS), which is a public institution. The SSIS manages facility information and QR code visit records, whereas the QR code-issuing company manages personal information such as the name and phone number of the person to whom the QR code has been issued. When a confirmed case of COVID-19 occurs and the KCDC needs information, the quarantine authority can request information from the SSIS, which keeps records of visits to the facility, and the QR code-issuing company, which keeps personal identifying information, to find out who (names and contact information) visited where and when.

By separating and encrypting visit records and personal information before storage, only quarantine authorities are enabled to view personal information as a

preventative measure to reduce privacy infringement. In addition, the electronic entry and exit registrations are stored only for four weeks, after which the facility visit records are automatically deleted. However, since this is also a centralized system, personal information is not protected if the government forcibly links related systems to track information. Therefore, trust and transparency of the government operations are important.

5.2 Implications and limitations of the study

Based on the coping theory, this study proposed a research model that shows the path from contact tracing app users' stress to their full utilization of the app. This research model can be applied to various fields of technology diffusion and expands the scope of coping theory applications. To date, no vaccine or treatment for COVID-19 has been developed. The findings of this study can be used as a guide to maximize the potential benefits of contact tracing apps with the goal of preventing the spread of COVID-19. Quarantine authorities in each country can improve the utilization of contact tracing apps by reducing the possibility of privacy infringement through establishing transparency and trust. Even once a vaccine or treatment for COVID-19 is developed, the findings of this study can be used to prevent the spread of future infectious diseases. Given the findings of this study, the distributed system may be more effective than the centralized system for adoption of contact tracing apps, as the distributed system can relieve concerns about privacy infringement. Therefore, the findings of this study can provide insights to quarantine authorities or app developers who want to deeply understand the tensions that arise when applying ICTs to prevent spread of infectious diseases and find innovative solutions. This study verifies the important role of ICTs in this current pandemic climate of COVID-19 and contributes to maximization of the potential benefits of contact tracing apps.

In this context, specific and unique implications of the current study are as follows:

First, the current study shows that users are less likely to appraise the strengths and benefits of the app in terms of challenging opportunities as they have more privacy concerns over contact tracing apps. Thus, those countries which utilize mandatory centralized contact tracing apps should implement policies that place more emphasis on relieving user's privacy concerns.

Second, the authorities should offer promotions and training programs that elucidate benefits and strengths of contact tracing apps in controlling the spread of COVID-19. For example, untraceable COVID-19 cases had increased from 4.7% (May 2020) to 14% (August 2020) in South Korea where only infected or those who contacted the infected are required to install the app. On the other hand, the Chinese case shows significantly lower rate of untraceable cases as the Chinese government requires all residents, regardless of their infection status, to install the contract tracing app. Such case can serve as a circumstantial evidence for the strength of contact tracing apps for ending the spread of COIVD-19. Therefore, South Korean government should also implement Internet-Pass QR code not only in facilities at risk

of mass infection but also more universally as the case of China. Another possible solution, if there is a high public concern for such mandatory installation of centralized apps, decentralized apps could be required for all residents of South Korea.

Finally, authorities and social activities should focus on users to have positive conviction toward contact tracing apps in order for users to understand the strength of contact tracing apps and take benefits of the apps.

This study has the following limitations. First, this study did not account for the differences in values as well as cultural and political aspects of the countries in which users of contact tracing apps live. Second, the survey conducted on Chinese app users cannot be said to represent all contact tracing apps. Third, an actual comparison study between the central and distributed systems regarding users' concerns is recommended.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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