Weather Information Acquisition and Health Significance during Extreme Cold Weather in a Subtropical City: A Cross-sectional Survey in Hong Kong

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Abstract Health and disaster risk reduction are important and necessary components in building a smart city, especially when climate change may increase the frequency of extreme temperatures and the health risks of urban dwellers. However, limited knowledge is available about the best way to disseminate weather warnings and health protection information. This study explores the weather information acquisition patterns of the Hong Kong public and examines the sociodemographic predictors of these patterns to establish the potential public health implications of smart city development. A population-based, stratified cross-sectional, random digit dialing telephone survey was conducted among the Cantonese-speaking population aged over 15 years in Hong Kong in early 2016. Analyses were conducted based on 1017 valid samples, with a response rate of 63.6%. Cold Weather Warnings were well disseminated in Hong Kong, with 95.7% of the respondents reporting awareness of the public warnings. Television and smartphone apps were the two most important channels for weather information acquisition. Age and education level are the main social-demographic variables associated with the current utilization and future preference of smartphone technology. Among those who were not using a preferred

channel to acquire weather information, 61.3% considered switching to a smartphone app. Moreover, the patterns of individual health protection measures and self-reported health impacts were significantly different between smartphone app users and non-users. Weather information dissemination should be tailored to the sociodemographic characteristics of the users.

Keywords Cold weather warnings · Public health emergencies · Smart cities · Subtropical city · Weather information dissemination systems

1 Introduction

In the twenty-first century, climate change has increased the frequency and intensity of extreme temperature events (CRED and UNISDR 2015). Impacts of extreme temperature events could be far-reaching if societies fail to cope with them effectively. Abundant epidemiological evidence has established a causal relationship between mortality and cold weather (Carder et al. 2005; Anderson and Bell 2009; Goggins et al. 2013a). Myocardial infarction, ischemic heart disease, cerebrovascular disease, acute respiratory distress, and hypothermia have been found to worsen during cold surges (Hassi 2005; Leung et al. 2008; Sena et al. 2014). The temperature-mortality/morbidity relationship varies greatly by latitude and climatic zone (Keatinge et al. 2000; Curriero et al. 2002; McMichael et al. 2006; Falagas et al. 2009; Goggins and Chan 2017), and cold impacts and how communities may respond to them in a subtropical metropolis like Hong Kong warrants more investigation.

Preparedness is key in emergency and disaster risk management. An established warning system not only enhances local capacity to limit losses caused by hazards,

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but also minimizes potential health impacts (WHO 2015). The application of new technologies, especially information and communication technologies, has been integrated into a global smart city movement in urban development around the world in recent years.

Weather information dissemination systems built on information communication technology are significant for protecting the well-being of communities, especially during extreme climatic events (Chan et al. 2012; Goggins et al. 2013b; Laaidi et al. 2013; Goggins and Chan 2017). Social media, in particular, assume an increasingly important role in information dissemination and household preparedness before and during disasters (Cretikos et al. 2008; Yin et al. 2014). Social media could be used ranging from delivering and receiving disaster preparedness information, warnings and signals, to detecting disasters in pre-disaster periods, and (re)connecting community members following disasters (Houston et al. 2015). Social media might also enhance the effectiveness of disaster risk communication, and thereby uplift disaster preparedness, response, and recovery from events that threaten the public's health (Merchant et al. 2011).

Despite the smart city movement, patterns of weather information acquisition of the public have yet to be studied. People's preferred information acquisition channels have seldom been examined. Scientific evidence is urgently needed to facilitate policies and best practices in disaster health risk communications. Understanding of current and preferred weather information acquisition channels could urge the weather information providers to improve communication to better meet user needs (Demuth et al. 2011). Since awareness is one of the necessary prerequisites for public health control (Last 1998), a far-reaching weather information channel is crucial for the public, not only to receive weather information but also to promote their preparedness against weather hazards. This study aims to examine how the public in the subtropical metropolis of Hong Kong acquires its weather information, to identify the sociodemographic patterns of information acquisition behavior, and to establish the public health significance of using smartphone apps during a cold surge.

2 Extreme Cold Weather and Social Media in Hong Kong

Hong Kong ranks fourth in terms of population density (6958 people per km²) in the world (World Bank 2016). With the recent rise in the intensity and frequency of extreme weather events (Hong Kong SAR Environment Bureau 2015), the city is facing higher risks of health-related impacts.

Located in a subtropical region, Hong Kong's average annual temperature is around 23.3 °C.¹ In January 2016, Hong Kong experienced its coldest winter in 59 years. A Cold Weather Warning was issued and the lowest temperature recorded by the Hong Kong Observatory (HKO) was 3.3 °C on 24 January 2016 during a persisting cold surge period. The temperature on Tai Mo Shan, the highest peak in Hong Kong, dropped to −6 °C. More than 120 people were trapped in the hill due to poor road condition and over 60 people were taken to hospitals for treatment (Hong Kong Observatory 2016a). The Education Bureau announced a suspension of classes and the Home Affairs Department opened temporary cold shelters and provided blankets for the needy.

In Hong Kong, the public obtains its weather information through different channels, including traditional media like radio, television, newspapers, and an information hotline, as well as internet-based media like websites and smartphone apps. Each channel has its own advantages and limitations. For example, weather forecast TV programs have become an integral part of local culture for more than 30 years, while smartphone apps have been receiving increasing interest during the past decade. The smartphone technology provides real-time updates via notifications and allows a certain degree of personalized customization. Users can choose the kind of weather information they would like to receive updates on.

3 Method

A population-based, stratified cross-sectional, random digit dialing telephone survey was conducted. Data on sociodemographic background, general public's weather information acquisition pattern, self-reported health outcomes, and individual health prevention measure during cold weather were collected among the Cantonese-speaking population aged over 15 years in Hong Kong in early 2016. Descriptive statistical analysis, Pearson's χ^2 test, Fisher's exact test, and multiple logistic/linear regressions were adopted in statistical analysis.

3.1 Data Collection

The telephone survey was conducted in Hong Kong between 28 January and 4 February 2016 when the minimum temperatures ranged from 9.4 to 16.2 °C (Hong Kong Observatory 2016b, c). Data collection was completed within 8 days, after the strongest cold wave in 59 years

¹ The temperature referred to in this article is the actual outdoor temperature recorded by the Hong Kong Observatory in the city center where most of the city activities occur.

(Hong Kong Observatory 2016a). A random digit dialing method was used to select households randomly from a full list of land-based telephone numbers in Hong Kong and interviewees were chosen randomly using the last birthday method (Chan et al. 2008). Quota sampling was used to ensure the demographic representation of the general population, with quotas based on age, sex, and residential district in Hong Kong (Rubin et al. 2009). Respondents were required to be 15 years old or above and to be able to speak Cantonese. Up to five calls were made before the telephone number was considered invalid, and all calls were made in the evening on weekdays and the whole day on weekends to prevent overrepresentation of the unemployed segment of the population.

The questionnaire design was based on previous studies in similar population contexts that examined self-reported health outcomes in winter (Chan et al. 2015a, b). A structured questionnaire in Chinese was developed, from which 22 close-ended questions are covered in this article. The collected information relates to (1) sociodemographic characteristics (including age, gender, residential districts, educational attainment, and marital status); (2) current and preferred channels of weather information acquisition; (3) smartphone ownership; (4) awareness of climatic conditions during the cold surge period (including the perceived minimum temperature on the survey day and the issuance of Cold Weather Warnings); (5) individual health protection measures (including putting on warm clothes, avoiding prolonged exposure to wintry winds, using heaters, ensuring adequate indoor ventilation, paying extra attention to the conditions of elderly people and people with chronic medical conditions, paying extra attention to children, and keeping track of the weather forecast); and (6) health-related behavior (including appetite, mood, quality of sleep, and cold-related symptoms).

A pilot study ($n = 53$) was conducted in December 2015 to test the reliability of the questionnaire. Verbal consent was obtained before the interview, and each interview lasted for about 15–20 min. The study was approved by the Survey and Behavioral Research Ethics Committee of The Chinese University of Hong Kong (dated 13 January 2016).

3.2 Statistical Analysis

A descriptive statistical analysis was conducted on the sociodemographic characteristics of the participants, and differences in the proportions between the demographic characteristics in the study sample and the Hong Kong Population Census data in 2011 (Hong Kong SAR Census and Statistics Department 2012) were examined. The statistical significance of the associations using Pearson's χ^2 test and Fisher's exact test were calculated. Bivariate

analyses were conducted to identify significant associations among variables. Smartphone ownership and weather information mobile app usage rate were mapped out by districts. Multiple logistic regressions were used separately to evaluate independent predictors of smartphone app usage and preference. Multiple linear regression was also performed to model the perceived temperature error among the Hong Kong population. The perceived temperature error was defined as the square of the difference between the perceived and actual temperature, to weaken a small difference (that is, a difference between -1 and 1) while penalizing a big difference. Demographic variables and variables on temperature were tried in the models. Cook's distance and studentized residuals were used to indicate influential data points (Jacoby 2005). All statistical analyses were conducted using R version 3.1.3. Statistical significance was set at $\alpha = 0.05$ two-sided.

4 Results

Analyses were conducted based on 1017 valid samples, with a response rate of 63.6%. Social-demographic characteristics of the survey participants, weather information acquisition pattern, and the public health significance of smart weather information acquisition during the cold weather were analyzed and interpreted.

4.1 Demographic Characteristics of the Survey Participants

Through the cross-sectional telephone survey, 1017 valid samples were collected, and the response rate was 63.6% (1017/1598). The sociodemographic characteristics of the study population were comparable to the general population in Hong Kong in 2011 (Hong Kong SAR Census and Statistics Department 2012) (Table 1). The proportion of people aged 65 and over, female, and post-secondary graduate was slightly higher than the pattern of the Hong Kong Census 2011. Overall, no statistically significant difference was found between the sample and the census population in age, gender, education, residential districts, and marital status.

4.2 Weather Information Acquisition

Cold Weather Warnings were well disseminated in Hong Kong, with 95.7% of the respondents reporting awareness of the public warnings. Television and smartphone apps were the two most important channels for weather information acquisition. Older and less educated people were less likely to use and prefer smartphone technology. Among those who were not using a preferred channel to

Table 1 Sociodemographic characteristics of the survey respondents in January/February 2016 and the general population in Hong Kong in 2011 (Hong Kong SAR Census and Statistics Department 2012)

Demographics	Sample population		Hong Kong population 2011	Sample versus census <i>P</i> value ^a
	n	%	%	
Age (n = 1017)				0.82
15–24	126	12.4	14.0	
25–44	315	31.0	35.5	
45–64	384	37.8	35.4	
≥65	192	18.9	15.1	
Gender (n = 1017)				0.78 ^b
Male	437	43.0	46.0	
Female	580	57.0	54.0	
Education (n = 1015)				0.15
Primary	137	13.5	22.7	
Secondary	501	49.4	50.0	
Post-secondary	377	37.1	27.3	
Residential districts (n = 1015)				0.98
Hong Kong Island	182	17.9	18.2	
Kowloon	315	31.0	29.9	
New territories	518	51.0	52.0	
Marital status (n = 1012)				0.92 ^b
Single	410	40.5	42.2	
Married	602	59.5	57.8	

^a χ^2 test was used to measure the overall difference in proportions between this survey and the 2011 Hong Kong Population Census data. *P* value < 0.05 indicates significant difference

^b χ^2 test with continuity correction was used

acquire weather information, 61.3% reported the intention to switch to use a smartphone app in the near future.

4.2.1 Pattern of Weather Information Acquisition

Among all of the survey participants, television (50.1%) was the most popular channel people reported using, followed by smartphone apps (32.0%) and radio (8.4%). However, when asked about the preferred channels, smartphone apps (45.6%) were reported to be the most popular channel, followed by television (36.3%).

Figure 1 compares the current and preferred channels of receiving weather information among the survey participants. The entries were asymmetric with respect to the main diagonal, suggesting that some respondents might not be using their preferred channel. A total of 73.1% (737/1008) of respondents were using their preferred channel. The figure shows that 333 participants were using television and preferred using the same tool, and 128 were using television but preferred smartphone apps. Among those who were not using their preferred channel to acquire weather information, 61.3% considered switching to a smartphone app (166/271). Smartphone apps are most

likely to become the most preferred weather information acquisition dissemination channel in the near future.

In the age-stratified analysis, radio was found to have the most stable number of users in terms of current and preferred method. For people aged 45 to 64, 12.5% were currently using radio and 11.7% indicated a preference for using radio for weather information acquisition. For those older than 65, 12.5% were currently using radio for weather information acquisition and 14.1% expressed continuous preference to use radio for this purpose. Smartphone apps (41.2%) were the most preferable channel among those aged 45–64. No significant gender differences were found in the use and preference of weather information reception.

4.2.2 Residential Districts and Weather Information Acquisition

Smartphone ownership penetration is an important enabling factor to promote smart information dissemination systems. Among the survey respondents, 86.6% owned a smartphone. Figure 2a shows a geographical difference in smartphone ownership penetration among the 18 districts in Hong Kong. Except for district 15—Wan Chai

Fig. 1 Comparison between current and preferred channels of weather information acquisition in Hong Kong, January/February 2016. *Note* The rows refer to the current channels and the columns refer to the preferred channels. *Larger circles indicate larger numbers of people. The number in each circle is the actual frequency. The circles on the main diagonal represent those who were using their preferred channel. Numbers less than 5 were not shown in the graph*

Smartphone ownership penetration:

• <70% • 70-80% • 80-90% • >90%

App usage rate:
the density of the lined shading

(a)

(b)

Fig. 2 Smartphone ownership penetration and usage rate of mobile apps as the main source of weather information (app usage rate) in Hong Kong by district in January/February 2016. *Note a* the numbers represent the 18 districts (in alphabetical order): 1 Central and

Western, 2 Eastern, 3 Island, 4 Kowloon City, 5 Kwai Tsing, 6 Kwun Tong, 7 North, 8 Sai Kung, 9 Sha Tin, 10 Sham Shui Po, 11 Southern, 12 Tai Po, 13 Tsuen Wan, 14 Tuen Mun, 15 Wan Chai, 16 Wong Tai Sin, 17 Yau Tsim Mong, 18 Yuen Long

(57.1%), district 3—Island (72.2%), district 17—Yau Tsim Mong (76.7%), and district 11—Southern (77.4%), the smartphone ownership penetration in other districts in Hong Kong was higher than 80%. An inverse relationship was observed between smartphone ownership penetration and age. It was 100% for survey participants aged 15–34, but only 55% for survey participants aged over 65. The percentage of smartphone ownership penetration in Wai Chai district was observed as extremely low because the proportion of study participants older than 65 years was the highest in this district. In addition, a scatterplot shows the relationship between smartphone ownership penetration and smartphone app usage rate (Fig. 2b). Interestingly, district 14—Tuen Mun had high smartphone ownership penetration but a low weather information app usage rate.

4.2.3 Who Tends to Prefer and Use a Smartphone for Weather Information Acquisition

Simple logistic regressions of sociodemographic factors (age, gender, educational attainment, residential districts, and marital status) on preferred and current use of smartphone apps for weather information acquisition were examined. Educational attainment, age, and marital status were significantly associated with both the preference and current use of smartphone apps to acquire weather information. In multiple logistic regressions, only older age and lower education level remained significantly associated with lower smartphone app usage and preference. The results on both the preferred and current use of smartphone apps for weather information acquisition were consistent and are listed in Table 2.

4.3 Public Health Significance of Smart Weather Information Acquisition During a Cold Wave in Hong Kong

There are significant differences in individual health prevention measures and self-reported health impact between smartphone app users and non-users.

4.3.1 Discrepancy Between Perceived and Actual Temperature

According to the study findings, 95.7% of the survey participants were aware of the Cold Weather Warning during the cold surge in the week before the survey. Among all surveyed respondents, 95.5% reported voluntarily keeping track of weather information. Female survey participants were more aware of the warning (96.5%) than male survey participants (94.6). The youngest survey participants, in the 15–24 age group, had the lowest awareness of the warning (93.5%).

Respondents were also asked about the minimum temperature on the interview day, and 69.0% (701/1016) of respondents indicated that they knew the minimum temperature. A total of 371 participants could recall the temperature within a ± 1 °C range between the minimum actual temperature as recorded by the Hong Kong Observatory and the perceived temperature. They could thus legitimately be regarded as having reasonable awareness of the weather conditions of the day.

As gender, age, the day's actual minimum temperature, and smartphone app use for receiving weather information were significantly associated with perceived temperature error in simple linear regression, a multiple linear regression was performed using these four significant variables as explanatory variables. The unadjusted and adjusted coefficients and corresponding 95% confidence interval (CI) are shown in Fig. 3. Since the interaction term between gender and actual minimum temperature was significant, the gender variable was forced into the final model with respect to the hierarchy principle which demands that all lower-order terms corresponding to a significant interaction be retained in the model (Faraway 2016). We found that male and higher actual minimum temperature were significant and strong predictors of large perceived temperature error, while smartphone app usage and age were non-significant in the multiple regression.

Outliers were detected by Bonferroni p-values for studentized residuals. Ten observations with Bonferroni p-values less than 0.05 were identified, with the deviations between the perceived and actual temperature ranging from 5.6 to 8.9 °C. Two of them were smartphone app users while the rest were non-app users, the probabilities of outlier occurrence were 0.9 and 1.7%, respectively.

4.3.2 Relationship Between Smart Weather Information Acquisition and Health Protection and Health Impacts in the Cold Wave

Individual uptake of health protection measures and the relationship with smartphone app use are listed in Table 3. Smartphone app users were more likely to use heaters and avoid prolonged exposure to wintry winds, but they were less likely to ensure adequate indoor air ventilation. In addition, χ^2 tests also found that survey participants who had a smaller difference between perceived and actual temperature were more likely to pay extra attention to the conditions of elderly people and people with chronic medical conditions (odd ratio, OR = 1.34, 95% confidence interval, CI 1.03–1.74), and pay extra attention to children (OR = 1.45, 95% CI 1.12–1.89).

Self-reported health impacts of the cold wave, stratified by the use of smartphone apps, are shown in Table 4. Significant differences of changes in the level of appetite

Table 2 Simple and multiple logistic regression analyses of the key demographics towards the use of smartphone apps for weather information acquisition in Hong Kong in January/February 2016

Characteristics	Preference of smartphone apps n = 1000				Current use of smartphone apps n = 1007			
	Unadjusted		Adjusted		Unadjusted		Adjusted	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Education								
Primary	1		1		1		1	
Secondary	3.34 (2.09, 5.33)	<0.01	1.83 (1.10, 3.03)	0.02	4.64 (2.36, 9.09)	<0.01	2.49 (1.23, 5.04)	0.01
Post-secondary	6.34 (3.92, 10.26)	<0.01	2.62 (1.53, 4.48)	<0.01	10.34 (5.56, 21.48)	<0.01	4.32 (2.09, 8.90)	<0.01
Age								
15–24	1		1		1		1	
25–44	0.87 (0.56, 1.33)	0.51	0.73 (0.46, 1.16)	0.18	1.17 (0.77, 1.77)	0.47	1.06 (0.67, 1.68)	0.79
45–64	0.40 (0.27, 0.61)	<0.01	0.37 (0.22, 0.61)	<0.01	0.45 (0.29, 0.68)	<0.01	0.50 (0.30, 0.84)	0.01
≥65	0.10 (0.06, 0.17)	<0.01	0.11 (0.06, 0.21)	<0.01	0.09 (0.04, 0.17)	<0.01	0.13 (0.06, 0.27)	<0.01
Marital status								
Single	1		1		1		1	
Married	0.76 (0.59, 0.98)	0.03	1.37 (0.98, 1.91)	0.07	0.66 (0.51, 0.87)	<0.01	1.15 (0.80, 1.63)	0.45

1017 valid samples were collected in this study, 1000 and 1007 cases were included due to the missing data in these two regression models respectively

OR odd ratio; CI confidence interval

	Unadjusted		Adjusted	
	Beta (95% CI)	P-value	Beta (95% CI)	P-value
<u>Gender</u>				
Male	4.62 (3.74, 5.51)	<0.01	-8.08 (-12.69, -3.47)	<0.01
Female	2.86 (2.11, 3.61)	<0.01	-3.75 (-9.39, 1.88)	0.13
<u>Age</u>	0.42 (0.34, 0.49)	<0.01	0.15 (-0.04, 0.33)	0.13
<u>Use smartphone to receive weather information mainly</u>				
No	3.31 (2.61, 4.00)		---	---
Yes	4.22 (3.19, 5.25)	<0.01	1.00 (-0.28, 2.29)	0.13
<u>Today's minimum temp.</u>	0.30 (0.25, 0.34)	<0.01	0.89 (0.56, 1.22)	<0.01
<u>Today's minimum temp. * Gender</u>	---	---	-0.47 (-0.91, -0.04)	0.03

Fig. 3 Factors associated with perceived temperature error in the cold 2016 winter of Hong Kong. Note 1017 valid samples were collected in Hong Kong in January/February 2016; 701 people who

indicated they knew the minimum temperature were included in the regression; CI confidence interval

and mood were observed using χ^2 test, though that of sleep quality and cold-related symptoms was found non-significant.

5 Discussion

This study identified the general pattern and associating predictors of weather information acquisition in Hong Kong. Given the high ownership penetration of

smartphones in Hong Kong, this study is an attempt to investigate the sociodemographic pattern of use specifically with respect to weather information dissemination. The number of survey participants who could recall the actual minimum temperature of the interview day was far lower than the number who claimed to know about the exact minimum temperature, even though almost all of the survey participants were aware of the Cold Weather Warning. Our results indicate that female participants were associated with less perceived temperature error. One

Table 3 Practice of individual health protection measures during the 2016 Hong Kong cold wave

Individual health protection measures	General (%)	Non-app users (%)	App users (%)	OR (95% CI)	P value
Put on warm clothes	95.9	96.0	95.7	0.92 (0.48–1.78)	0.82
Avoid prolonged exposure to wintry winds	82.2	79.3	88.2	1.94 (1.32–2.86)	<0.01
Use of heaters	59.2	55.4	67.1	1.64 (1.24–2.16)	<0.01
Ensure adequate indoor air ventilation	77.8	80.7	71.4	0.60 (0.44–0.81)	<0.01
Drink more warm water	80.8	81.3	79.8	0.91 (0.65–1.27)	0.58
Pay extra attention to the conditions of elderly people and people with chronic medical conditions	57.5	56.7	59.3	1.11 (0.85–1.46)	0.43
Pay extra attention to children	56.5	56.6	56.5	1.00 (0.76–1.30)	0.99
Keep track of weather forecast	95.5	94.8	96.9	1.71 (0.84–3.48)	0.14

1017 valid samples were collected in Hong Kong in January/February 2016

OR odd ratio; CI confidence interval

Table 4 Self-reported health impacts of cold weather by app users and non-users

Health impact		Non-app users			App users			P-value*	
		n	Yes	No	n	Yes	No		
Any cold-related symptom		694	68.5%	31.5%	322	68.2%	31.8%	0.94	
		Better (%)	Worse (%)	Neutral (%)			Better (%)	Worse (%)	Neutral (%)
Appetite	694	19.6	6.2	74.2	322	26.7	6.5	66.8	0.03
Sleep quality	694	11.0	22.0	67.0	322	15.5	21.7	62.7	0.11
Mood	693	1.4	21.9	76.6	322	4.3	19.6	76.1	0.01

1017 valid samples were collected in Hong Kong in January/February 2016

* χ^2 test was used

possible explanation could be that females paid more attention to detailed weather information because it is still common for females to assume a caregiver role.

The findings indicated that television and smartphone apps are currently two of the most popular channels for weather information acquisition. Television was still the leading channel so far, despite the rapid technology development. In the study, smartphone ownership was 86.6% among the survey participants. This is comparable to the smartphone penetration in Hong Kong, which is 85.8% (Hong Kong SAR Census and Statistics Department 2017). The proportion of weather information acquisition through smartphone apps as the main channel is only 32.0%. It was found that smartphone ownership is inversely related to age. There is a clear willingness of respondents to use smartphone apps for information acquisition. Smartphone apps may be the dominant weather information acquisition channel in the near future, taking into consideration the high usage rate among young people and that this channel is more preferred by those aged 45–64.

A classic public health theory, the “diffusion” theory (Roger 1995) provides a detailed illustration on how people respond to changes. According to the theory, the population can be divided into five groups based on their degree of moving towards changes. Moving along the curve, around 34% of people are considered a “late majority,” that is those who are slower to respond and generally need more effort to convince. Around 16% of the population is considered as “laggards.” They are the subgroup that shows little interest and does not want to be involved. This theory has significant public health implications for the potential inadequacy of a smart city. The evolving information and communication technology advancement is likely to outcast the “laggards,” in this case the older people. Smart city and advanced communication technologies imply a lot of opportunities to enhance public health and disaster risk reduction. However, it is not wise and even risky to assume that the benefits would rapidly diffuse to each subgroup of the community. Availability and accessibility of new information and communication

technology lay the basis for building a smart city, but much support is needed in order to realize the potential benefits. The benefits of a smart city can only be maximized if the community has the knowledge and is willing to be involved.

Individual health protection measures were not as widely adopted as expected in the community despite the high dissemination rate of the cold weather warning. A possible explanation may be that people failed to heed the information conveyed through the media they do not accept, and perceptions or beliefs may be important in determining compliance with official advice (Rubin et al. 2009). Generally speaking, the adoption of health protection measures by app users was not lower when compared with non-app users, except for ensuring adequate indoor air ventilation. However, ventilation is important for winter indoor air quality because there is evidence that house dust mites thrive under conditions of high relative humidity, and allergies to them are more frequent in mild humid winters (Daisey et al. 2003). A low ventilation rate is also one of the factors that can lead to increased incidence of respiratory diseases caused by viruses (Brundage et al. 1988; Fisk 2001). Future effort is needed to provide targeted information to improve actual personal health protection. Moreover, significant differences in the change of behavior were observed between app users and non-users, especially with respect to appetite and mood. A higher proportion of app users appeared to have better appetite and mood during a cold weather warning, though it is unclear why. Future studies will be required to clarify this finding.

A smart city aims to enhance the performance of traditional networks via the use of information and telecommunication technologies (Mohanty et al. 2016). The public health significance of weather information dissemination channels is amplified when coupled with health monitoring systems and systems controlling healthcare service delivery (Boulos et al. 2015; Hussain et al. 2015).

While smart weather information dissemination systems are essential to building a smart city, those who show less interest in or have no access to smartphone apps should not be ignored. This is especially important since many of these people are among the most vulnerable (the elder and the less educated, for example). For now, weather information providers should disseminate relevant information through different channels to address the stratified information acquisition pattern identified. In order to avoid the marginalization of community subgroups, more study is warranted to address the relationship of technology and its implication on public health promotion in the community.

This study has a number of limitations. The lack of spatial temperature data may affect the number of survey participants who were able to make a reasonable guess that fell within $\pm 1^\circ\text{C}$ in this article. The actual minimum

temperature referred to in this article is the one recorded at the Hong Kong Observatory headquarter located in the city center. Most social activities happen in the city center and this temperature should serve as a reasonable proxy. Second, this is a telephone survey and households without land-based telephone service may be missed. This is compensated by the high penetration rate of 94.1% fixed line telephones in Hong Kong (Hong Kong SAR Office of the Communications Authority 2016). Further, this is a study based on self-reporting and information bias may arise due to small round-offs on reported temperatures. All of the questions in the survey were close-ended, and this might have caused limited responses on the adoption of individual health protection measures. Yet, the measures stated are suggested by the Hong Kong Observatory when there is a Cold Weather Warning and should provide a reasonable picture on the overall adoption.

6 Conclusion

This study provides insight on the pattern of obtaining weather information during a cold surge period in a highly urbanized subtropical city. Although television holds its dominance in public communication, smartphone apps attract increasingly more people in Hong Kong, with their convenience, flexibility, and timeliness, especially for the young population. Overall, the use of smartphone apps demonstrates much potential for enhancing dissemination of weather information. Relevant public health policies should be tailored to the pattern of technology use and application.

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