Received: 29 March 2021 | Revised: 28 July 2021 | Accepted: 11 September 2021

DOI: 10.1111/1468-5973.12376

ORIGINAL ARTICLE

WILEY

Exploring whether wireless emergency alerts can help impede the spread of Covid-19

Hamilton Bean[1] | Nels Grevstad[2] | Abigail Meyer[1] | Alex Koutsoukos[1]

[1]Department of Communication, University of Colorado Denver, Denver, Colorado, USA

[2]Department of Mathematics and Statistics, Metropolitan State University of Denver, Denver, Colorado, USA

Correspondence
Hamilton Bean, Department of Communication, University of Colorado Denver, 1201 Larimer St., Denver, CO 80217, USA.
Email: hamilton.bean@ucdenver.edu

Funding information
The University of Colorado Denver's Office of Research Services (ORS)

Abstract

Officials worldwide have sought ways to effectively use mobile technology to communicate health information to help thwart the spread of Covid-19. This study offers a preliminary exploration of whether state-level ($N = 6$) and local-level ($N = 53$) wireless emergency alert (WEA) messages might contribute to impeding the spread of Covid-19 in the United States. The study compares changes in reported rates of infections and deaths between states and localities that issued WEA messages in March and April of 2020 with states that did not. Small sample sizes and differences in the rates of Covid-19 spread prohibit robust statistical analysis and detection of clear effect sizes, but estimated effects are generally in the right direction. Combining statistical analysis with preliminary categorization of both WEA message content and social media themes suggests that a positive effect from WEA messages cannot be ruled out.

KEYWORDS

Covid-19, risk communication, wireless emergency alerts

1 | INTRODUCTION

The United States and international officials have sought ways to effectively communicate health information to help thwart the spread of Covid-19, with mobile alerting via cell broadcast and/or SMS (short message service) technology emerging as an important tool. Cell broadcast uses a 'push' technology that sends messages to all enabled devices in a designated area, while SMS uses a point-to-point system and requires officials' prior knowledge of specific phone numbers. Early on, South Korea (Gold, 2020), Taiwan (Chen, 2020), and New Zealand (Matthews, 2020) were lauded for their ability to contain the spread of Covid-19, in part, through their intensive use of mobile alerting. Officials claim that mobile alerting can help slow the spread of Covid-19 by instructing people to take appropriate protective actions, such as social distancing, wearing masks, and washing hands (Gold, 2020). The World Health Organization (WHO) maintains a 'Covid-19 SMS Message Library' with templates that can be translated into multiple languages. The WHO urges 'telecommunications companies worldwide to support the delivery of these messages and unleash the power of communication technology to save lives from COVID-19' (2020, para. 1). Illustrating the reach of mobile alerting, on 25 March 2020, mobile device screens across New Zealand lit up with a cell broadcast message from the National Emergency Management Agency:

> This message is for all of New Zealand. We are depending on you. Follow the rules and STAY HOME. Act as if you have COVID-19. This will save lives. Remember: Where you stay tonight is where YOU MUST stay from now on. You must only be in physical contact with those you are living with (Majeed, 2020, para. 1–3).

In the United States, in late October 2020, Utah issued a statewide Covid-19 WEA message connected to the upsurge in Covid-19 infections nationwide:

> State of Utah: COVID-19 is spreading rapidly. Record cases. Almost every county is a high transmission area.

> Hospitals are nearly overwhelmed. By public health order, masks are required in high transmission areas. Social gatherings are limited to 10 or fewer (Asmelash & Toropin, 2020, para. 2).

'Be careful!' The message also warned, and it included an embedded reference hyperlink containing county-level portals for further information.

Even if health conditions do not call for statewide WEA issuance, communities can leverage the geolocation affordances of the WEA system. For example, also in October 2020, Massachusetts officials announced that communities at high risk for Covid-19 transmission would receive WEA messages reminding them about safety rules (Klein & Rosenberg, 2020).

These WEA messages stated:

> MAGovt Alert COVID19 is a serious threat in [city/town name]. Wear a mask. Wash your hands. Keep your distance. Do not share food drinks utensils. Stay home if sick. Get a free COVID test. Stop gatherings with family and friends. Protect you and your loved ones. For more info visit mass.gov/stopcovid19

Evidence supporting the efficacy of mobile alerting for Covid-19 is now beginning to emerge. While no nationwide mobile alert was issued in the United States, this study explores preliminary evidence that state-level ($N = 6$) and locality-level ($N = 53$) Wireless Emergency Alert (WEA) messages might contribute to impeding the spread of Covid-19. States included Colorado, Maryland, Michigan, New Mexico, South Carolina, and Florida. Localities refer to territory/county/municipal areas. Although the U.S. WEA system is used primarily for issuing severe weather warnings (i.e., for tornados, flood, snow squall, etc.), messages are also issued that can help protect lives and property from various types of hazards (fire, industrial accident, drinking water contamination, etc.). As of 2020, 'pandemic' has been added to the list of hazards for which WEA messaged are issued.

Research concerning the use of WEA messages to warn at-risk publics typically focuses on correlations between message attributes (i.e., source, hazard, guidance, timeframe, location, style, and map and URL inclusion) and recipients' interpretations (i.e., comprehension, belief, and personalization) and behavioural intentions and actions (i.e., protective action decision-making and response) (Bean et al., 2016; Casteel & Downing, 2016; Doermann et al., 2020; Kim et al., 2019; Kuligowski & Doermann, 2018; Liu et al., 2017; Sutton & Kuligowski, 2019; Sutton et al., 2018; Wood et al., 2018). By contrast, this study explores a novel set of correlations: changes in reported rates of Covid-19 infections and deaths between states and localities that issued WEA messages in March and April of 2020 with states that did not. Combining preliminary statistical analysis with an exploration of both WEA message content and social media responses to statewide Orders suggests that WEA messages could play an important role in instructing people to take protective actions that hinder Covid-19 transmission.

In what follows, we situate our exploratory study in the context of public warning and mobile health communication ('mHealth') research. We then describe the purpose and operation of the WEA system. We subsequently describe how the WEA system was used during the onset of the Covid-19 outbreak in the United States. Following a discussion of our research questions and methods, we offer three preliminary analyses of Covid-19 WEA messages: (a) statistical model comparisons between states and localities that issued WEA messages in March and April of 2020 and states that did not; (b) comparison of Covid-19 WEA messages with social science best practice for 'complete' messages; and (c) social media themes in response to the issuance of statewide Orders delivered over the WEA system. We conclude with several ideas for 'next steps' stemming from our analyses.

2 | PUBLIC WARNING AND MHEALTH

The study of public warning involves understanding why people take protective action in response to information and instruction about hazards and disasters (Drabek, 1986; Lindell & Perry, 2012; Mileti & Sorensen, 1990). Typically, this research asks disaster survivors to account for when and how they received, understood, and acted upon an alert or warning message, or it asks what stakeholders *might* do in a hypothetical situation. The results of this research are then used to help officials optimize their public warning systems to increase warning message reception, comprehension, and appropriate response (Ripberger et al., 2019).

Mobile technology offers new ways to conduct public warning (National Academies of Sciences Engineering and Medicine, 2018). However, the rapid development and implementation of mobile public warning systems have generally outpaced research concerning their actual benefits, limitations, and efficacy (Bean, 2019). Researchers have outlined a theoretical and applied communication research agenda for mobile public warning messages that involve studying (a) how hazard-related information can best be communicated in short messages, (b) how a map or other location-related information might be included, (c) how messages can be configured and disseminated to minimize delay time and maximize personalization, and (d) how contextual and message receiver factors influence mobile public warning reception, comprehension, and response (Bean et al., 2015; National Academies of Sciences Engineering and Medicine, 2018; Wood et al., 2018). These themes have also been taken up in the growing body of literature concerning 'terse' warning messages, a category of risk communication that includes both WEA messages and social media messages (Doermann et al., 2020; Kim et al., 2019; Sutton, Gibson, et al., 2015; Sutton, League, et al., 2015).

One research arena associated with mobile public warning research is mHealth (mobile health communication), defined as 'medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants, and other wireless devices' (World Health Organization, 2011, p. 6).

mHealth technology allows for 'place-shift' so that people can receive health messages when they are not able to easily access mass media (e.g., radio, television, or the Internet). mHealth messages can also reach publics when they are most amenable to behaviour change, such as when they need to take an immediate protective action to keep themselves and their loved ones safe from harm. mHealth messages delivered via the WEA system also have the benefit of extensive reach: Most members of the public own mobile devices and typically have them turned on and nearby.

The WEA system was not explicitly designed with a pandemic in mind (Bean, 2019). Although it is still unclear exactly what type of instructional communication within a WEA message is needed to maximize protective action among diverse audiences during a pandemic, mHealth has demonstrated its effectiveness in other contexts (Gold, 2020; Gurman et al., 2012). It is important to note, however, that mHealth campaigns typically involve personalized, repetitive, and 'opt in' SMS messages, whereas officials might view cell broadcast WEA messages as an impersonal 'bell ringer' designed to alert people located in a large geographic area (Bean, 2019). Adaptively tailoring WEA messages for smaller communities and frequently issuing them is possible, however (see Klein & Rosenberg, 2020), and a few U.S. communities used the WEA system in this way during the onset of the Covid-19 crisis. To our knowledge, this study is the first to explore the efficacy of mHealth-type messages issued via the WEA system during the 2020 Covid-19 pandemic.

3 | WIRELESS EMERGENCY ALERTS

The WEA system is a partnership between FEMA, the Federal Communications Commission (FCC), and the nation's wireless service providers. Launched in 2012, the WEA system is designed to enhance public safety by allowing authorized federal, state, and local officials to send 90-character (recently 360-character), geotargeted, text-like messages to the public's mobile devices during an emergency.

3.1 | Purpose

According to the FCC (2020a), the WEA system is an essential part of U.S. emergency preparedness and has been used more than 56,000 times to warn the public about dangerous weather, missing children, and other critical situations. The WEA system is designed to enable officials to send 'imminent threat' alerts, as well as AMBER alerts for missing and abducted children. A third type of alert, 'public safety message', became available for alert originators in July 2019 (related messages include recommendations for saving lives and property). A fourth type of alert, a 'presidential alert', allows the President of the United States to send a message to the entire nation in the event of a catastrophic disaster, such as a nuclear attack. All four alert types involve a text-like message that appears on the screen of the recipient's mobile device, accompanied by an audible attention signal and vibration. WEA messages can be issued in English and Spanish, and they may also include an 'embedded reference' hyperlink for additional information. The first three types of WEA messages can also be 'opted out' of, that is, turned off or blocked on one's mobile device. A presidential alert cannot be blocked. An example of a WEA message is provided in Figure 1.

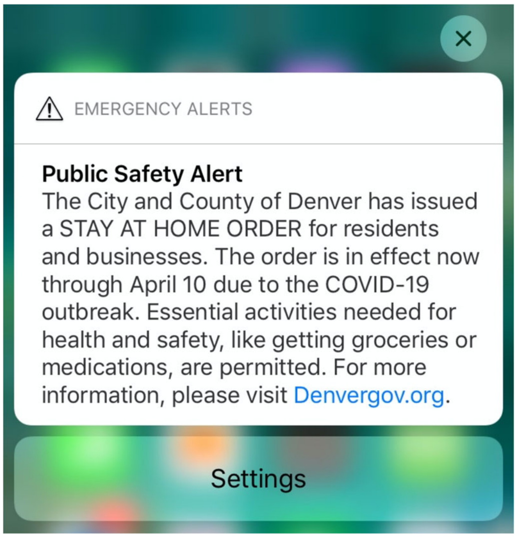

FIGURE 1 Denver wireless emergency alerts message, 24 March 2020 [Color figure can be viewed at wileyonlinelibrary.com]

3.2 | Operation

WEA messages reach mobile devices using cell broadcast technology that is less likely to become backlogged during times of network congestion, but what makes the WEA system truly unique is its ability to 'push' broadcast alert and warning messages to all mobile devices located in a geographic area specified by an alerting authority. Typically, an emergency manager can use a WEA system interface to draw a 'polygon' across a designated hazard area on a map rendered on a screen. The coordinates of the polygon are defined using latitude and longitude points. Once the WEA message is issued, cellular towers both within and just outside the polygon broadcast the WEA message to all enabled mobile devices in the designated alert area. The alert area can, in theory, be a small as a city block or as large as the entire nation.

Because WEA is an opt-out system, iOS and Android devices are sold to users opted-in to all categories of WEA messages by default (some devices also allow users to opt-in to WEA system tests at the local level). It is estimated that 99% of Americans receive wireless service from a provider that voluntarily participates in the WEA system. As of 20 May 2020, scores of emergency management and public safety organizations in each state have earned FEMA's authorization to issue WEA messages, although some states only have a relative handful of authorized alerting authorities.

3.3 | Assessment

The U.S. government has funded the lion's share of WEA-related research via the Department of Homeland Security (DHS) Science and Technology Directorate's First Responders Group. There are more than 25 WEA-related research publications listed on the DHS website. These studies can be grouped under the topics of (a) technical aspects of the WEA system and its integration with other systems, (b) geotargeting, (c) cybersecurity, (d) public education, sentiment, and response, (e) system and message diffusion, and (f) accessibility. The 2018 National Academies report, 'Emergency Alert and Warning Systems: Current Knowledge and Future Research', provided summaries of many of these studies, which range from broad reviews of prior research to narrow measurements of research participants' heartrates, skin conductance (sweaty palms), and other physiological responses when receiving experimental WEA messages. Most of these research projects were initiated around the same time as the WEA system began nationwide rollout in 2012. A synthesis of the research contained in the National Academies (2018) report is outside the scope of this study, but it is important to note that its authors concluded that 'fairly little is known about how to maximize the effectiveness of messages whose content is limited by technology constraints or policy decisions, or how best to make use of alerts and warnings in today's information-rich environments' (p. vii).

Importantly for this study, Doermann et al. (2020) recently proposed a short message creation tool for wildfire emergencies, which is a type of rapid WEA message generator. The authors reviewed 33 research publications regarding short alert message best practices to develop evidence-based guidance and a tool that officials can use to rapidly create informative and effective 360-character wildfire evacuation WEA messages. Information extracted from each research publication reviewed included: the topic, objectives, methods, findings, and recommendations. The authors related each information item to the Protective Action Decision Model (Lindell & Perry, 2012) to develop a tool that included five essential categories: message source, hazard identification, hazard location, timeframe, and guidance (sixth category, 'general', was also included, but not in relation to the research literature). Researchers have consistently demonstrated that these five categories are vital for public sensemaking and response irrespective of hazard type (National Academies of Sciences Engineering and Medicine, 2018). Doermann et al. (2020) claimed that issuing a 'complete' warning message makes it 'likely that even more people will take appropriate protective actions, and they will take them sooner (i.e., with less milling behaviour)' (p. 8). While wildfire and Covid-19 are extremely different hazards, they share the need for the public to take specific and timely protective action to reduce risks and save lives. Therefore, in this study, we assessed Covid-19 WEA messages for their 'completeness', that is, their inclusion of the five essential categories of information.

Finally, due to their forced reception, WEA messages can be seen as a privacy invasion, and missteps with the WEA system have generated a public backlash in some communities (Bean, 2019). We therefore assessed public reactions to the issuance of statewide Orders via the WEA system through preliminary scrutiny of social media themes (Facebook and Twitter). Our aim was to merely determine which themes were salient, as well as how these themes might reflect (or not) prior WEA research that has indicated that short messages (90- and 280-characters) can spark confusion and anxiety among recipients (Bean et al., 2015; Wood et al., 2018).

4 | WEA MESSAGES AND COVID-19

On 23 March 2020, *Washington Post* contributing reporter Dan Stillman published an article, 'My Cellphone Should Have Buzzed with a Coronavirus Emergency Alert' (Stillman, 2020). Stillman argued that WEA messages 'should be used immediately by states, localities and perhaps the president in the fight against the deadly virus' (para. 2). Stillman also reported that, a week earlier, FEMA had posted a monthly 'tip' for emergency managers indicating that WEA messages may be used to distribute public safety information about Covid-19. A FEMA spokesperson explained at that time that 22 agencies across 12 states and one territory had already issued WEA messages about Covid-19. FEMA's 'tip' stated that authorities could issue WEA messages to: (a) convey health orders, (b) detail curfew information, (c) notify communities of assembly guidelines/restrictions and (d) advise of other Covid-19-related information.

On the morning of 24 March 2020, the corresponding author forwarded Stillman's article and a link to FEMA's 'tip' to contacts in the Denver Office of Emergency Management. Coincidentally, that afternoon, the City and County of Denver issued the WEA message in Figure 1.

On 2 April 2020, FEMA subsequently released a Public Notice, 'Enhanced Wireless Emergency Alerts Available for Coronavirus Pandemic' (FCC, 2020b) that merely noted its earlier 'tip' guidance but did not reiterate or elaborate it. Aside from this Notice, there is scant evidence of national, state, and local WEA message policy guidance or coordination.

4.1 | Research questions

Integrating research concerning public warning, mHealth, and the WEA system, noted above, we generated the seven research questions below (grouped by theme). To repeat, this study tends to correlate WEA message issuance with recipients' interpretations (i.e., comprehension, belief, and personalization) and behavioural intentions and actions (i.e., protective action decision-making and response) (Bean et al., 2016; Casteel & Downing, 2016; Doermann et al., 2020; Kim et al., 2019; Kuligowski & Doermann, 2018; Liu et al., 2017; Sutton & Kuligowski, 2019; Sutton et al., 2018; Wood et al., 2018). It is important to note that the public warning, mHealth, and the WEA system literature does not anticipate correlating WEA message issuance with disease case rates and death rates, as we do herein.

Because some states issued state-wide Orders, but not statewide WEA messages, we compared states that issued statewide WEA messages with states that did not issue WEA messages but did issue statewide Orders. Also, because some states issued neither statewide Orders nor WEA messages, we compared the states that issued statewide WEA messages with states that issued neither Orders nor WEA messages. For non-WEA issuing states, we marked day zero as the date the U.S. National Emergency was declared: 13 March 2020. A handful of U.S. localities issued WEA messages (sometimes multiple messages) in March and April 2020. Issuance occurred in states that both did and did not issue statewide Orders or WEA messages. We compared county-level per capita increases in rates of Covid-19 cases and deaths 30 days and 60 days after the first WEA message issuance with states that issued no WEA messages. We recognize that we are comparing counties with states, but we do not have a rationale for picking non-WEA message-issuing counties for comparison. We wanted to see whether Covid-19 case and death *rates* were lower, per capita, in counties that issued WEA messages compared with per capita cases and deaths in states that did not.

As mentioned above, recent studies have compared WEA-type messages to social science best practices for short public warning messages (Doermann et al., 2020; Sutton & Kuligowski, 2019). These studies suggest that 'complete' warning messages may generate better protective action outcomes because recipients will not need to 'mill' for additional and confirming information. We, therefore, asked two research questions related to localities. To gain a better understanding of how WEA message recipients reacted to Covid-19 messages, we inductively analysed Facebook comments and Twitter posts to identify broad social media themes following the issuance of statewide Orders via WEA messages.

5 | METHODS

To obtain data for this study, the first author contacted FEMA on 26 April 2020, about its Covid-19 response efforts and was provided with a spreadsheet summary of Covid-19 related WEA messages to date (produced for internal tracking purposes). The first author was informed that further updates to the spreadsheet would not be available. The FEMA spreadsheet included the WEA issuance data used in this study (available from the corresponding author upon request). The FEMA spreadsheet includes: (a) states and localities that issued WEA messages; (b) issuance date; and (c) the text of the messages sent. To repeat, states included Colorado, Maryland, Michigan, New Mexico, South Carolina, and Florida. Localities specified in the FEMA spreadsheet ranged from locations such as 'Cook County, IL', to 'Areas of Manatee County, FL', to 'Areas of Los Angeles County, CA' to 'Areas of UT, AZ, and NM' (Navajo Nation–no separate Covid-19 case and death rates for Navajo Nation were available for this study, however).

To supplement FEMA's spreadsheet, the authors integrated data from the Johns Hopkins University & Medicine website and *Washington Post* coronavirus tracking website including: (a) population figures for states and localities that issued Covid-19 WEAs (and states that did not); (b) date of statewide Covid-19 Order (if applicable); (c) reported Covid-19 cases and deaths on date of WEA issuance; (d) reported Covid-19 cases and deaths 30 days after the date of WEA issuance; and (e) reported Covid-19 cases and deaths 60 days after the date of WEA issuance.

To address the first five research questions (Q1–Q5), we evaluated summary statistics and the results of model fitting to the Covid-19 cases and deaths data. Covid-19 cases (and deaths) were modelled via an exponential growth model (Bertozzi et al., 2020),

$$I(t) = I_0 \times e^{\alpha t}, \tag{1}$$

where $I(t)$ is the cumulative number of cases (or deaths) at time t, I_0 is the initial number of cases (or deaths) at time $t = 0$ (the date of WEA issuance), e is the exponential constant, and α is the rate constant at which individuals infect others (or at which cumulative deaths grow). A smaller value of α corresponds to a slower rate of transmission (or growth in deaths). The actual rate at which the cumulative number of cases (or deaths) increases, however, also depends on the value of I_0. A larger value of I_0 results in much faster growth in the number of cases (or deaths). Intuitively, the more people that are infected, the faster the number of infections grows. Thus, even if one state's transmission rate α is lower than another's, for example, due to Order or WEA issuance, it can have a substantially higher cumulative number of cases (or deaths) at $t = 30$ or 60 days if it's starting number I_0 was higher. The doubling time is the time it takes to double the number of cumulative infections (or deaths) and is a common measure of how fast the contagion spreads: if we start with $\overline{I}$ infections, then at time

$$T_d = \frac{\ln 2}{\alpha}, \tag{2}$$

we achieve $2 \times \overline{I}$ infections. A smaller value of α corresponds to a longer doubling time. The doubling time does not depend on the value of I_0.

Because Model (1) is parsimonious, it is well suited to developing policy-relevant insights into the pandemic (Bertozzi et al., 2020). To investigate whether WEAs lower the transmission rate α (or slow the growth rate of deaths) and lengthen the doubling time T_d, we modelled α as a function of whether or not a state (or county) issued a WEA:

$$\alpha = \begin{cases} \alpha_0 & \text{if no WEA,} \\ \alpha_0 + \Delta\alpha & \text{if WEA.} \end{cases}$$

A negative value of $\Delta\alpha$ implies a lower Covid-19 transmission rate (or slower growth rate of deaths) and longer doubling time when WEAs are issued.

The values of $I_{0,}\alpha_0$ and $\Delta\alpha$ are estimated from the data on Covid-19 cases and deaths by fitting Model (1) to the data. We used the glmer() function from the lme4 package in R (Bates et al., 2015) to fit the model via maximum likelihood. More specifically, we fitted a generalized linear mixed-effects model, with Poisson response variable (cases or deaths), that included time (days after issuance of WEA), WEA (a variable indicating whether a WEA was issued), and their interaction all as fixed effects, and for each state a random intercept and random time coefficient. The model also included (log of) population as an offset to control for differences in population sizes across states (or counties). To test statistically whether the transmission rate was lower when a WEA was issued, that is, whether $\Delta\alpha$ was negative, we used a Wald *Z* test.

Because not all states and counties had the same exposure and transmission risk at the beginning of the pandemic, a negative $\Delta\alpha$ could potentially result from WEA message-issuing states (and counties) having a lower propensity for exposure and transmission even in the absence of the WEA messages. Factors such as preponderance of health communication, adequacy of health and safety protocols at workplaces, schools, and other public venues, and presence of transportation hubs (such as airports), workplace concentrations, and economic activity centres could lead to baseline differences in risk of exposure and transmission between states (and counties) that issued WEA messages and those that did not. Degree of compliance with health and safety protocols (as influenced by ideology, media bubbles, and countervailing guidance) and availability of testing are other potential contributing factors. A thorough assessment of whether such a discrepancy existed between states and counties that issued WEAs and those that did not is beyond the scope of our study. However, we note that the level of outbreak at time $t = 0$ (in mid-March and early April 2020) was actually slightly higher, on average, for the states and counties that issued WEAs than for those that did not (Tables 1–10), although the reasons for this are unclear.

In addition to statistical comparisons, all 213 messages contained in the FEMA spreadsheet were analysed for their 'completeness'. We added columns in the FEMA spreadsheet for the five essential categories of message source, hazard identification, hazard location, timeframe, and guidance (Doermann et al., 2020), as well as a column for whether or not an 'embedded reference' hyperlink was included. The fourth author then assessed whether each message included information related to each category. The short length of each message allowed for rapid identification of the presence or absence of the information types. The first author then repeated the fourth author's analysis to ensure accuracy, discussing and/or adjusting a handful of minor discrepancies. An example coded Covid-19 WEA message is given in Figure 2.

To identify social media themes, in August 2020 the third and fourth authors examined public posts on the official Twitter and Facebook accounts of five states whose governors issued stay-at-home Orders via statewide WEA messages: Colorado ($N = 905$), Maryland ($N = 467$), Michigan ($N = 1791$), New Mexico ($N = 668$), and

TABLE 1 Mean numbers of cases and deaths per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that did and did not issue WEAs

		Mean cases per 100k			Mean deaths per 100k		
Statewide WEA	Sample size	0 days	30 days	60 days	0 days	30 days	60 days
No	44	17.6 (3.1)	217.5 (41.4)	439.1 (65.3)	0.35 (0.11)	8.82 (1.79)	21.12 (4.22)
Yes	6	22.9 (5.6)	219.9 (42.8)	442.6 (91.8)	0.36 (0.14)	12.38 (4.08)	25.46 (7.08)

Note: Standard errors of the means are in parentheses.

TABLE 2 Estimated initial per capita cases and deaths (at date of issuance), Covid-19 transmission rate, growth rate of deaths, and doubling times in states that did and did not issue wireless emergency alerts (WEAs)

	Cases			Deaths		
Statewide WEA	Initial number (I_0) per 100k	Transmission rate (α)	Doubling time (T_d) (days)	Initial number (I_0) per 100k	Growth rate (α)	Doubling time (T_d) (days)
No	27.9	0.0404	17.2	0.80	0.0443	15.7
Yes	49.9	0.0359	19.3	1.90	0.0412	16.8

TABLE 3 Mean numbers of cases and deaths per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that did and did not issue WEAs (but did issue Orders)

		Mean cases per 100k			Mean deaths per 100k		
Statewide WEA	Sample size	0 days	30 days	60 days	0 days	30 days	60 days
No	36	21.2 (3.5)	253.6 (48.7)	479.6 (77.6)	0.42 (0.13)	10.56 (2.09)	24.77 (4.96)
Yes	6	22.9 (5.6)	219.9 (42.8)	442.6 (91.8)	0.36 (0.14)	12.38 (4.08)	25.46 (7.08)

Note: Standard errors of the means are in parentheses.

TABLE 4 Estimated initial per capita cases and deaths (at date of issuance), Covid-19 transmission rate, growth rate of deaths, and doubling times in states that did and did not issue wireless emergency alerts (WEAs) (but did issue Orders)

	Cases			Deaths		
Statewide WEA	Initial number (I_0) per 100k	Transmission rate (α)	Doubling time (T_d) (days)	Initial number (I_0) per 100k	Growth rate (α)	Doubling time (T_d) (days)
No	37.7	0.0365	19.0	1.22	0.0412	16.8
Yes	49.9	0.0359	19.3	1.92	0.0410	16.9

TABLE 5 Mean numbers of cases and deaths per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that issued both WEAs and Orders and states that issued neither

		Mean cases per 100k			Mean deaths per 100k		
Statewide Order, WEA	Sample size	0 days	30 days	60 days	0 days	30 days	60 days
Neither	8	1.3 (0.9)	55.1 (5.5)	256.7 (50.6)	0.01 (0.01)	0.97 (0.25)	4.69 (0.91)
Both	6	22.9 (5.6)	219.9 (42.8)	442.6 (91.8)	0.36 (0.14)	12.38 (4.08)	25.46 (7.08)

Note: Standard errors of the means are in parentheses.

TABLE 6 Estimated initial per capita cases and deaths (at date of issuance), Covid-19 transmission rate, growth rate of deaths, and doubling times in states that issued both wireless emergency alerts (WEAs) and Orders and states that issued neither

	Cases			Deaths		
Statewide Order, WEA	Initial number (I_0) per 100k	Transmission rate (α)	Doubling Time (T_d) (days)	Initial Number (I_0) Per 100k	Growth rate (α)	Doubling Time (T_d) (days)
Neither	7.2	0.0579	12.0	0.11	0.0609	11.4
Both	49.9	0.0359	19.3	1.92	0.0410	16.9

TABLE 7 Mean numbers of cases and deaths per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for counties that issued WEAs and states that did not

		Mean cases per 100k			Mean deaths per 100k		
WEA	Sample size	0 days	30 days	60 days	0 days	30 days	60 days
No	24 (states)	14.4 (3.5)	221.8 (57.0)	451.3 (98.4)	0.20 (0.07)	9.68 (2.97)	24.17 (7.18)
Yes	53 (counties)	25.5 (6.8)	179.1 (32.8)	413.5 (73.5)	0.45 (0.18)	6.70 (1.16)	17.38 (3.89)

Note: Standard errors of the means are in parentheses.

TABLE 8 Estimated initial per capita cases and deaths (at date of issuance), Covid-19 transmission rate, growth rate of deaths, and doubling times in counties that issued wireless emergency alerts (WEAs) and states that did not

	Cases			Deaths		
WEA	Initial number (I_0) per 100k	Transmission rate (α)	Doubling time (T_d) (days)	Initial number (I_0) per 100k	Growth rate (α)	Doubling time (T_d) (days)
No	23.9	0.0410	16.9	0.67	0.0456	15.2
Yes	24.7	0.0385	18.0	0.69	0.0416	16.7

South Carolina (N = 1094). These accounts were analysed inductively and iteratively to better understand public responses to the statewide Orders issued via the WEA system. Inductive and iterative thematic analysis of media content is an established approach within Communication Studies (Foss, 2017). As Tracy (2013) states in *Qualitative Research Methods: Collecting Evidence, Crafting Analysis, Communicating Impact*, researchers using this approach hold loosely to tentative explanations and categories and compare them to emergent data. The approach is designed to shed light on emerging problems (the problem here appears to be message insufficiency, as we discuss below). We, therefore, did not set out to pinpoint mutually exclusive content categories derived from prior research, and we acknowledge that our categorization scheme allows for items to be interpreted differently or in ways that span multiple categories.

TABLE 9 Mean numbers of cases and deaths per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for counties that issued 'complete' WEAs and states that did not issue WEAs

WEA	Sample size	Mean cases per 100k 0 days	30 days	60 days	Mean deaths per 100k 0 days	30 days	60 days
No	24 (states)	14.4 (3.5)	221.8 (57.0)	451.3 (98.4)	0.20 (0.07)	9.68 (2.97)	24.17 (7.18)
Yes	4 (counties)	18.5 (4.8)	129.4 (63.3)	265.6 (161.6)	0.14 (0.09)	5.68 (2.92)	13.78 (9.86)

Note: Standard errors of the means are in parentheses.

TABLE 10 Estimated initial per capita cases and deaths (at date of issuance), Covid-19 transmission rate, growth rate of deaths, and doubling times in counties that issued 'complete' wireless emergency alerts (WEAs) and states that did not issue WEAs

	Cases			Deaths		
WEA	Initial number (I_0) per 100k	Transmission rate (α)	Doubling time (T_d) (days)	Initial number (I_0) per 100k	Growth rate (α)	Doubling time (T_d) (days)
No	23.9	0.0410	16.9	0.66	0.0460	15.1
Yes	30.4	0.0296	23.4	0.61	0.0407	17.0

The Health Officer of Santa Clara County has issued a shelter-in-place order, effective 12:01
source / location **guidance**

a.m. Tuesday, March 17, 2020, to help prevent the spread of COVID-19. For more information
time **hazard**

on the order, including exceptions for essential activities and FAQs, visit www.sccphd.org/cv19
embedded reference

FIGURE 2 Example Covid-19 wireless emergency alert message coded for completeness

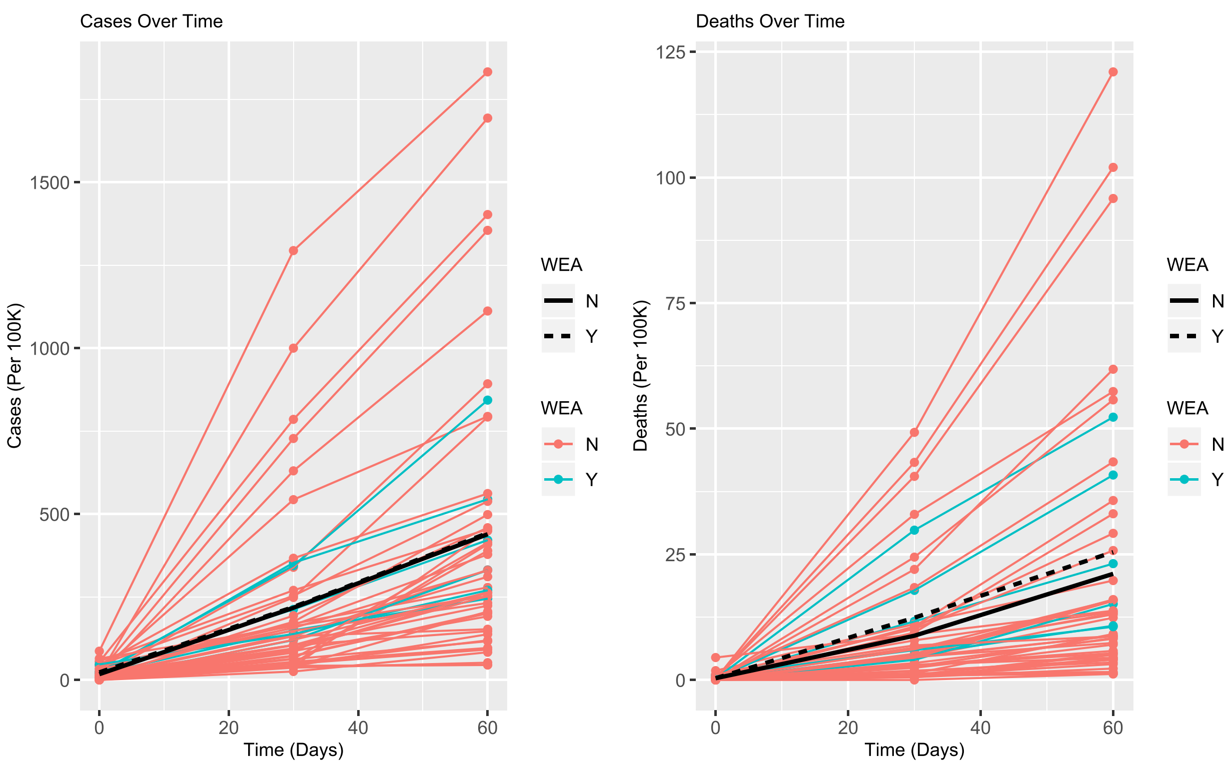

FIGURE 3 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that did and did not issue WEAs. Red and green lines are individual states. Black lines are the observed means (from Table 1) [Color figure can be viewed at wileyonlinelibrary.com]

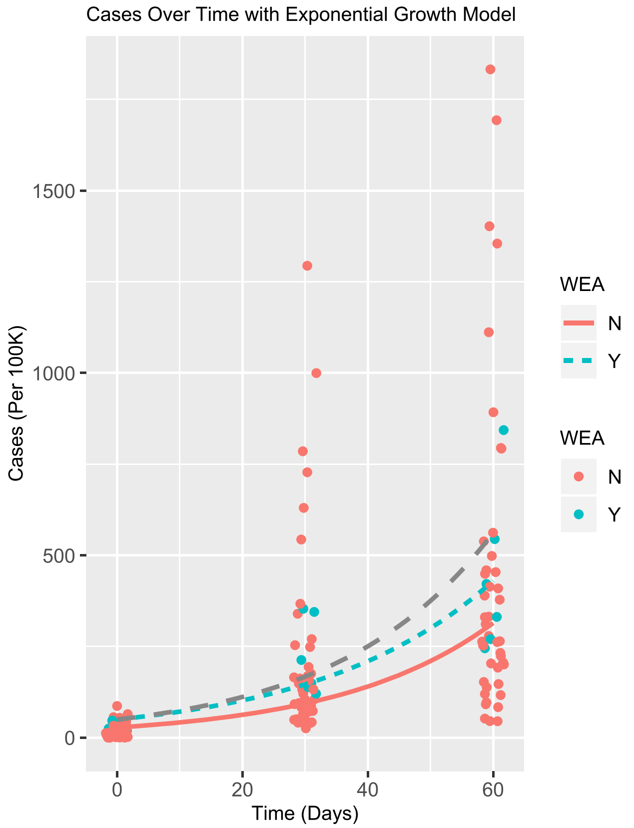

FIGURE 4 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that did and did not issue WEAs. Red and green points are individual states. The red and green curves show the fitted exponential growth model $I(t)$ for states that did and did not issue WEAs. The grey dashed curve shows the expected exponential growth trajectory for states that issued WEAs if their transmission rates (or growth rates for deaths) had been the same as those of states that did not issue WEAs (i.e., if $\Delta\alpha$ had been 0) [Color figure can be viewed at wileyonlinelibrary.com]

We make no claims that these categories rigidly account for all possible interpretations or should serve as the basis for subsequent research. Rather, the categorization scheme presented in this study simply provides a starting point for what researchers can expect to see when conducting their own investigations of Covid-19-related WEA message social media themes.

We assessed the content of the governors' accounts' 'comments' or 'responses' sections directly, categorizing posts in relation to emergent themes, and iteratively repeating the analysis as themes multiplied or narrowed. While these accounts did not post images of the actual WEA messages issued, a handful of users did post images of the WEA message in the comments or responses section. Other official state-level accounts that posted the actual WEA message exhibited so little engagement that thematic analysis was impossible. For example, the Colorado Department of Homeland Security and Emergency Management posted an image of the state's 26 March 2020, stay-at-home Order WEA message on Facebook, but it elicited only five responses. The Maryland Emergency Management Agency (MEMA) posted a message on 30 March 2020, that stated, 'This afternoon, MEMA will help to issue a Wireless Emergency Alert (WEA). The alert system is used to send important, life-saving information to Marylanders. Please, remain calm but PLEASE heed the warning too'. However, MEMA did not post the actual WEA message to its Facebook account. Likewise, we could not locate an official posting of Michigan's statewide WEA message. We, therefore, used the Order-related posts on the governors' Facebook and Twitter accounts as an analogue for that same day's WEA message because the content of the social media posts and WEA messages were similar. A sixth state to issue a statewide WEA message, Florida, was omitted from our analysis because we were unable to find official Twitter or Facebook posts related to either Florida's 28 March 2020, WEA issuance or its 2 April 2020, implementation of its Order. Florida Governor Ron DeSantis' Twitter account reveals that no posts were made on the aforementioned dates, respectively. We found that, similarly, Governor DeSantis' Facebook profile did not offer any posts specifically regarding Florida's statewide Order or WEA message.

Roughly 4900 responses to official announcements of states' respective Orders were associated with nine categories based on the prevalence of the theme found within the social media responses, including *supportive*, *opposing*, *hysteria* (conspiracy theories or nonsense), *seeking clarity* (including criticism), *calls for stricter measures*, *calls for government financial support*, *doubting the efficacy of the Order*, *critical of the government's late response*, and *unrelated* (irrelevant or unclear). To repeat, the categories were generated inductively and iteratively, with the third and fourth authors working in tandem to develop the categories as they scrutinized the social media responses, assigning each response to a category. After the first round

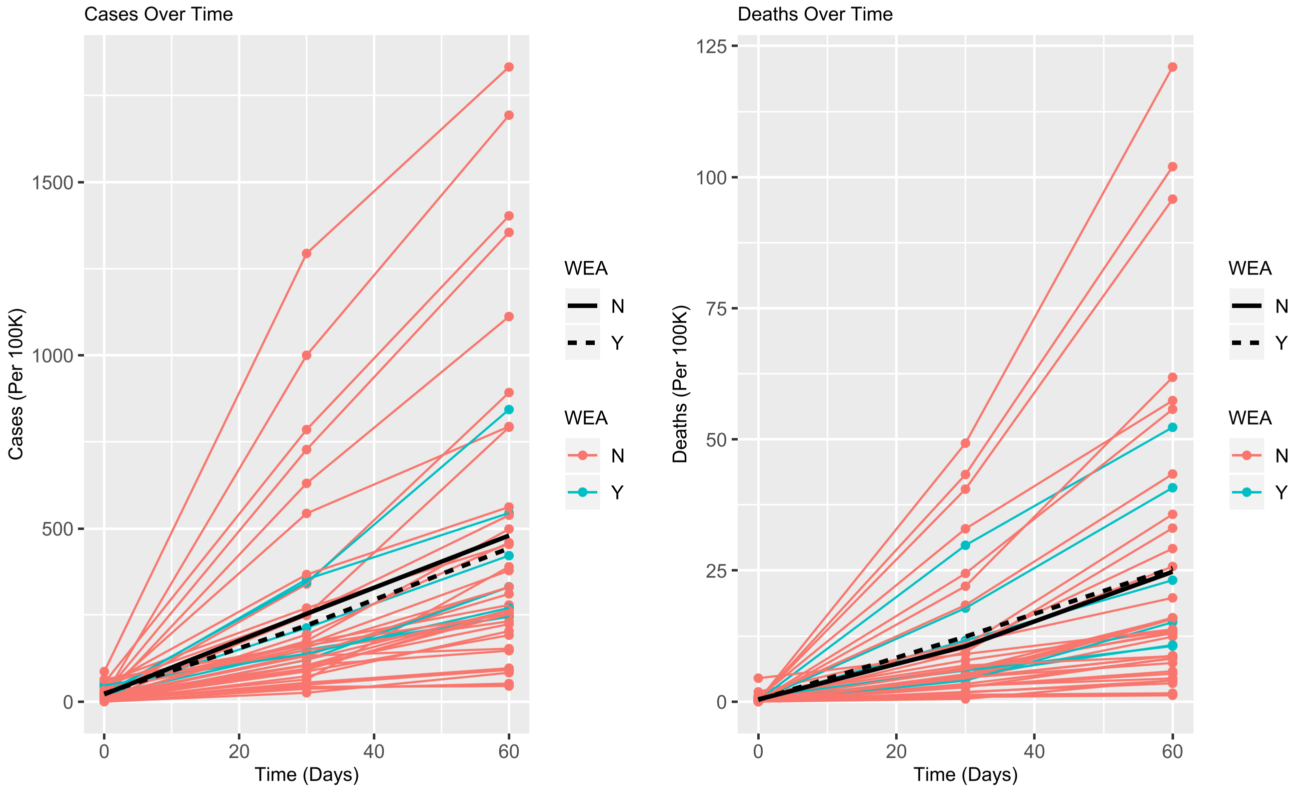

FIGURE 5 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that did and did not issue WEAs (but did issue Orders). Red and green lines are individual states. Black lines are the observed means (from Table 3) [Color figure can be viewed at wileyonlinelibrary.com]

of category development, the authors had established six categories. However, a significant proportion of the responses had been assigned to an 'unclear' category. We subsequently developed three additional categories to account for these responses ('financial support', 'doubting efficacy', and 'critical of late response'). The third and fourth authors repeated their analysis, assigning each response to one of the nine categories. The first author then repeated the entire analysis to assess its reasonableness, obtaining similar category counts for each state's social media responses. We did not formally establish intercoder reliability for this exploratory study and, therefore, presume that responses could be categorized differently; however, our aim was simply to identify themes within the social media responses that would be apparent to the casual observer, which our generalized approach enabled. We next present the findings of our comparative, 'completeness', and thematic analyses.

6 | COMPARING COVID-19 WEA MESSAGE ISSUANCE AMONG STATES AND LOCALITIES

6.1 | Results for Q1

The six states that issued statewide WEA messages (and Orders) during March or April 2020 had a higher mean number of cases per capita on the date of issuance than the 44 states that did not issue WEAs, but the difference in means narrowed after 30 and 60 days (Table 1 and Figure 3). Those six states also had a slightly higher mean number of deaths per capita on the date of issuance, as well as 30 and 60 days later.

The estimated Covid-19 transmission rate parameters (and standard errors of the estimates) are $\alpha_0 = .0404$ (SE = 0.0019) and $\Delta\alpha = -.0045$ (SE = 0.0055), based on fitting Model (1) to the data on cases. The negative sign of $\Delta\alpha$ suggests a lower transmission rate and longer doubling time when WEAs are issued (Table 2 and Figure 4), although the effect is not statistically significant ($z = -0.805$, $p = .210$). The model-based estimate of the mean number of cases per capita on the date of issuance (I_0) is higher for WEA-issuing states than for those that did not issue WEAs.

The estimated growth rate parameters for deaths are $\alpha_0 = .0443$ (SE = 0.0056) and $\Delta\alpha = -.0031$ (SE = 0.0042). The negative sign of $\Delta\alpha$ suggests a slower growth rate and longer doubling time when WEAs are issued (Table 2 and Figure 4), although the effect is not statistically significant ($z = -0.741$, $p = .229$). The estimated mean number of deaths per capita on the date of issuance (I_0) is higher for WEA-issuing states than for those that did not issue WEAs.

6.1.1 | Results for Q2

The six states that issued statewide WEA messages (and Orders) during March or April 2020 had a higher mean number of cases per

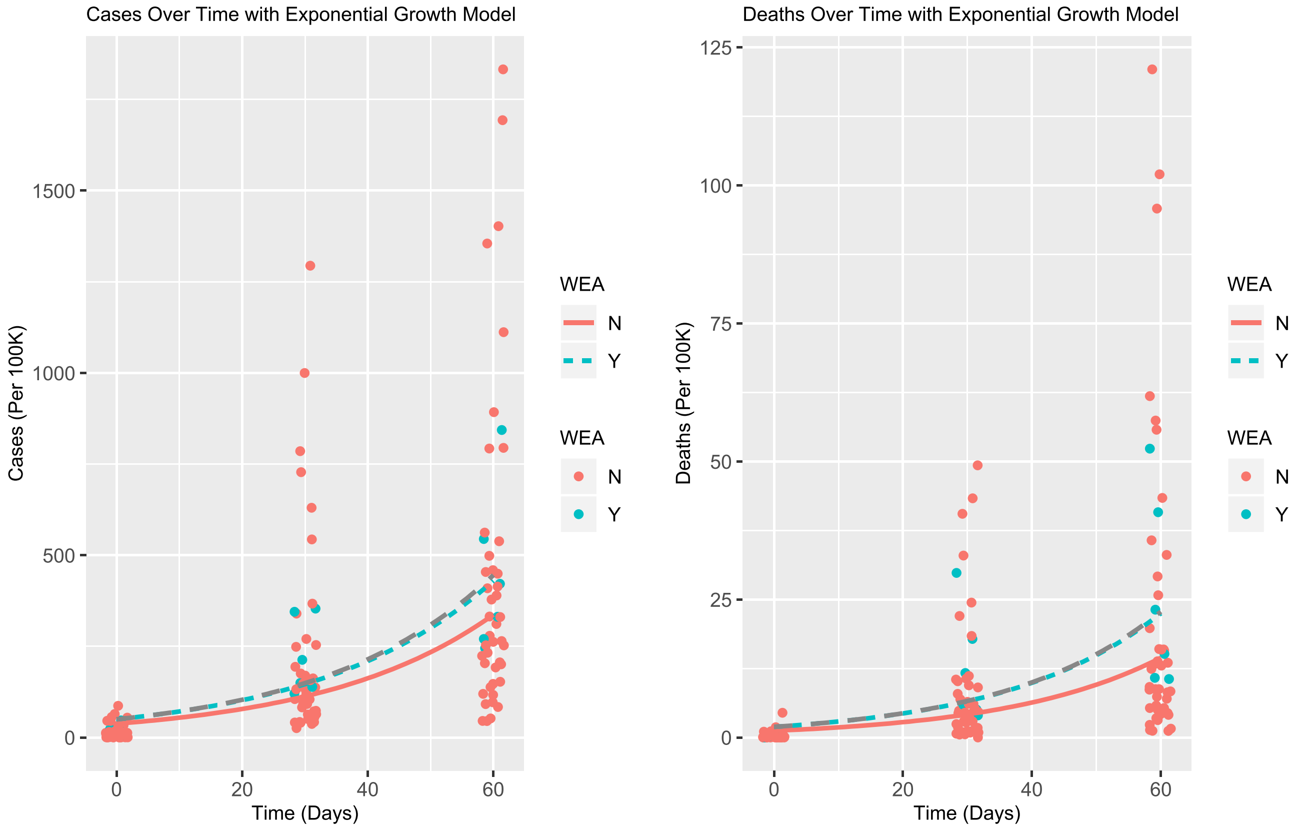

FIGURE 6 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that did and did not issue WEAs (but did issue Orders). Red and green points are individual states. The red and green curves show the fitted exponential growth model $I(t)$ for states that did and did not issue WEAs (but did issue Orders). The grey dashed curve shows the expected exponential growth trajectory for states that issued WEAs if their transmission rates (or growth rates for deaths) had been the same as those of states that did not issue WEAs (but did issue Orders) (i.e., if $\Delta\alpha$ had been 0) [Color figure can be viewed at wileyonlinelibrary.com]

capita on the date of issuance than the 36 states that issued statewide Orders but not WEA messages but had a lower mean after 30 and 60 days (Table 3 and Figure 5). Those six states had a lower mean number of deaths per capita on the date of issuance than the states that issued Orders but not WEAs, but they had a slightly higher mean at 30 and 60 days.

The estimated Covid-19 transmission rate parameters are $\alpha_0 = .0365$ (SE = 0.0015) and $\Delta\alpha = -.0006$ (SE = 0.0039), based on fitting Model (1) to the data on cases. The negative sign of $\Delta\alpha$ suggests a slightly lower transmission rate and longer doubling time when WEAs are issued (Table 4 and Figure 6), although the effect is not statistically significant ($z = -0.150$, $p = .440$). The estimated mean number of cases per capita on the date of issuance (I_0) is higher for WEA-issuing states than for those that did not issue WEAs.

The estimated growth rate parameters for deaths are $\alpha_0 = .0412$ (SE = 0.0014) and $\Delta\alpha = -.0002$ (SE = 0.0036). The negative sign of $\Delta\alpha$ suggests a slightly slower growth rate and longer doubling time when WEAs are issued (Table 4 and Figure 6), although the effect is not statistically significant ($z = -0.062$, $p = .475$). The estimated mean number of deaths per capita on the date of issuance (I_0) is higher for WEA-issuing states than for those that did not issue WEAs.

6.1.2 | Results for Q3

The six states that issued statewide WEA messages (and Orders) during March or April 2020 had a substantially higher mean number of cases per capita on the date of issuance than the eight states that issued neither Orders nor WEA messages, and also had a higher mean after 30 and 60 days (Table 5 and Figure 7). Those six states also had a substantially higher mean number of deaths per capita on the date of issuance and after 30 and 60 days.

The estimated Covid-19 transmission rate parameters are $\alpha_0 = .0579$ (SE = 0.0043) and $\Delta\alpha = -.0220$ (SE = 0.0066), based on fitting Model (1) to the data on cases. The negative sign of $\Delta\alpha$ indicates a substantially lower transmission rate and substantially longer doubling time when both WEAs and Orders are issued (Table 6 and Figure 8), and the effect is statistically significant ($z = -3.351$, $p = .001$). The estimate of the mean number of cases per capita on the date of issuance (I_0) is substantially higher for states that issued both WEAs and Orders than for those that issued neither.

The estimated growth rate parameters for deaths are $\alpha_0 = .0609$ (SE = 0.0037) and $\Delta\alpha = -.0200$ (SE = 0.0047). The negative sign of $\Delta\alpha$ indicates a slower growth rate and longer doubling time when both WEAs and Orders are issued (Table 6 and Figure 8), and the effect is

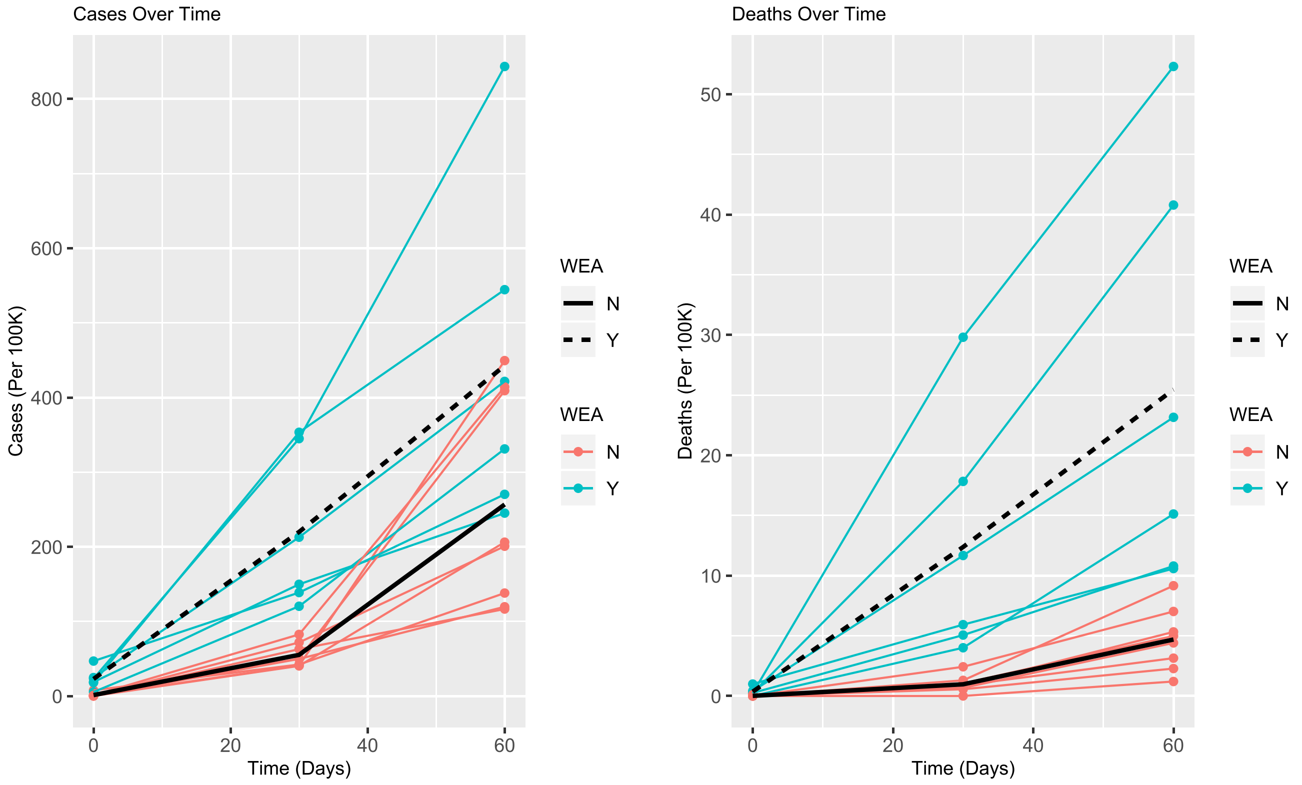

FIGURE 7 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that issued both WEAs and Orders and states that issued neither. Red and green lines are individual states. Black lines are the observed means (from Table 5) [Color figure can be viewed at wileyonlinelibrary.com]

statistically significant ($z = -4.284$, $p = .000$). The estimated mean number of deaths per capita on the date of issuance (I_0) is substantially higher for states that issued both WEAs and Orders than for those that issued neither.

6.1.3 | Results for Q4

The 53 localities that issued WEA messages during March or April 2020 had a substantially higher mean number of cases per capita on the date of issuance than the 24 states that issued no statewide WEA messages, nor issued any county- or municipal-level WEA messages, but they had a lower mean after 30 and 60 days (Table 7 and Figure 9). Those 53 counties had a mean number of deaths per capita on the date of issuance that was more than double the mean for the 24 states that issued no WEA messages but had a considerably lower mean than those states at 30 and 60 days.

The estimated Covid-19 transmission rate parameters are $\alpha_0 = .0410$ (SE = 0.0033) and $\Delta\alpha = -.0025$ (SE = 0.0040), based on fitting Model (1) to the data on cases. The negative sign of $\Delta\alpha$ suggests a lower transmission rate and longer doubling time when WEAs are issued (Table 8 and Figure 10), although the effect is not statistically significant ($z = -0.627$, $p = .265$). The estimated mean number of cases per capita on the date of issuance (I_0) is slightly higher for WEA-issuing counties than for states that did not issue WEAs.

The estimated growth rate parameters for deaths $\alpha_0 = .0456$ (SE = 0.0021) and $\Delta\alpha = -.0040$ (SE = 0.0028). The negative sign of $\Delta\alpha$ suggests a slower growth rate and longer doubling time when WEAs are issued (Table 8 and Figure 10), although the effect is not statistically significant ($z = -1.46$, $p = .072$). The estimated mean number of deaths per capita on the date of issuance (I_0) is slightly higher for WEA-issuing counties than for states that did not issue WEAs.

6.1.4 | Results for Q5

The four communities that issued 'complete' WEA messages during March or April 2020 had a higher mean number of cases per capita on the date of issuance than the 24 states that issued no statewide WEA messages, nor issued any county- or municipal-level WEA messages, but they had a considerably lower mean at 30 and 60 days (Table 9 and Figure 11). Those four communities had a lower mean number of deaths per capita on the date of issuance as well as 30 and 60 days afterward.

The estimated Covid-19 transmission rate parameters are $\alpha_0 = .0410$ (SE = 0.0031) and $\Delta\alpha = -.0114$ (SE = 0.0084), based on fitting Model (1) to the data on cases. The negative sign of $\Delta\alpha$ suggests a lower transmission rate and longer doubling time when 'complete' WEAs are issued (Table 10 and Figure 12), although the effect is not statistically significant ($z = -1.35$, $p = .088$).

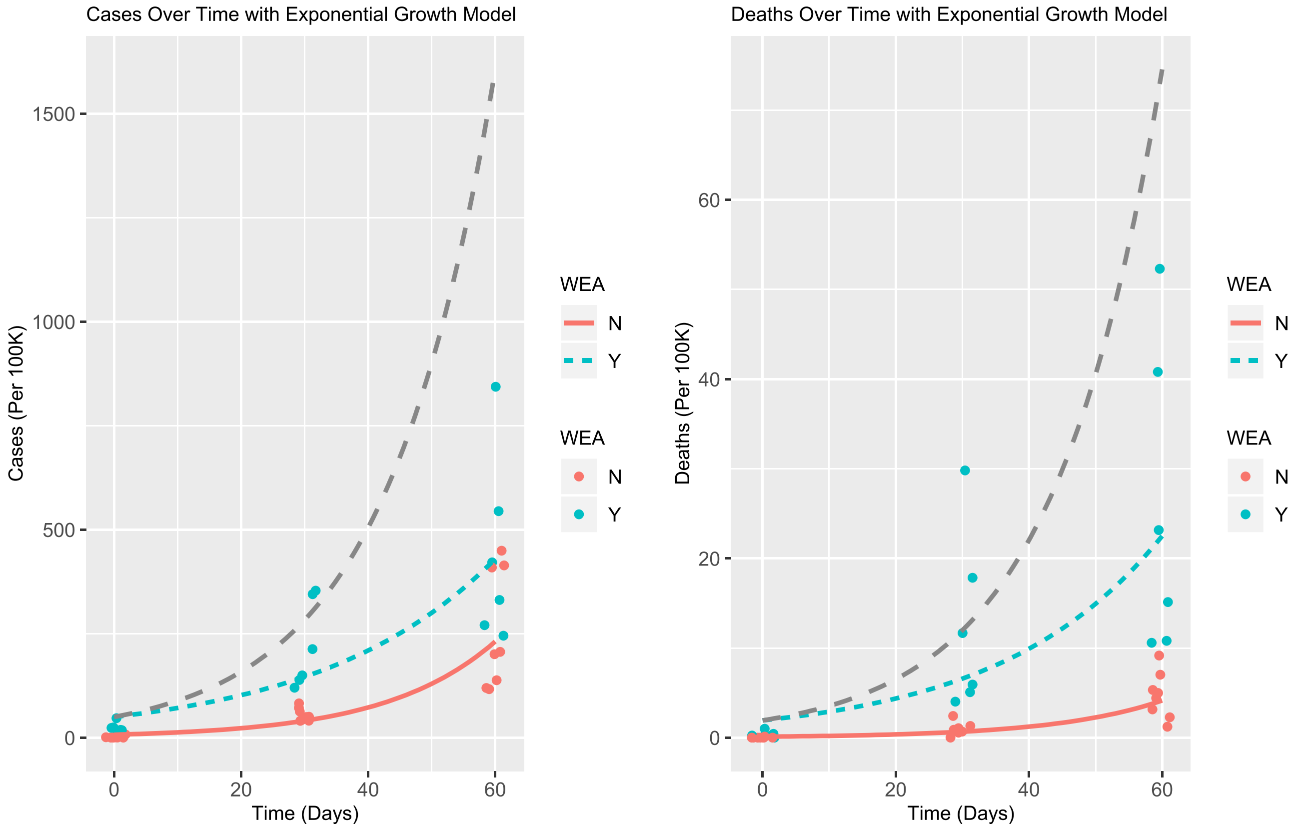

FIGURE 8 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for states that issued both WEAs and Orders and states that issued neither. Red and green points are individual states. The red and green curves show the fitted exponential growth model $I(t)$ for states that issued both WEAs and Orders and states that issued neither. The grey dashed curve shows the expected exponential growth trajectory for states that issued both WEAs and Orders if their transmission rates (or growth rates for deaths) had been the same as those of states that issued neither (i.e., if $\Delta\alpha$ had been 0) [Color figure can be viewed at wileyonlinelibrary.com]

The estimated mean number of cases per capita on the date of issuance (I_0) is higher for 'complete' WEA-issuing counties than for states that did not issue WEAs.

The estimated growth rate parameters for deaths are $\alpha_0 = .0460$ (SE = 0.0023) and $\Delta\alpha = -.0053$ (SE = 0.0075). The negative sign of $\Delta\alpha$ suggests a slower growth rate and longer doubling time when 'complete' WEAs are issued (Table 10 and Figure 12), although the effect is not statistically significant ($z = -0.71$, $p = .239$). The estimated mean number of deaths per capita on the date of issuance (I_0) is lower for 'complete' WEA-issuing counties than for states that did not issue WEAs.

In sum, for all five research questions Q1–Q5, there is some evidence that WEA messages might be effective in lowering Covid-19 transmission rates and growth rates in cumulative deaths, but the observed effects are not statistically significant except in conjunction with the effect of an Order (Q3). The nonsignificance of statistical test results may be explained by relatively small sample sizes, especially for Q5.

The six states that issued statewide WEA messages during March or April 2020 saw markedly lower Covid-19 transmission rates and, to a lesser extent, slower growth rates in deaths after message issuance than the 44 states that did not issue WEA messages (Q1).

Those observed effects diminish, however, when the non-Order-issuing states are removed from the comparison group. In this case, the six states that issued WEA messages (and Orders) saw only slightly lower transmission rates and only slightly slower growth rates in deaths than the 36 states that issued statewide Orders but not WEA messages (Q2).

On the contrary, the observed effects of WEAs increase substantially, and become statistically significant, when the Order-issuing states are removed from the comparison group. In this case, the six states that issued WEA messages (and Orders) saw dramatically lower transmission rates than the eight states that issued neither statewide Orders nor WEAs, and they also saw dramatically slower growth rates in deaths (Q3).

The 53 counties that issued WEA messages during March or April 2020 saw lower Covid-19 transmission rates and, to a greater extent, slower growth rates in deaths after message issuance than the 24 states that issued neither statewide nor non-statewide WEA messages (Q4).

The effects of 'complete' countywide WEA messages were even more pronounced. The four counties that issued 'complete' WEA messages during March or April 2020 saw considerably lower transmission rates and somewhat slower growth rates in deaths after

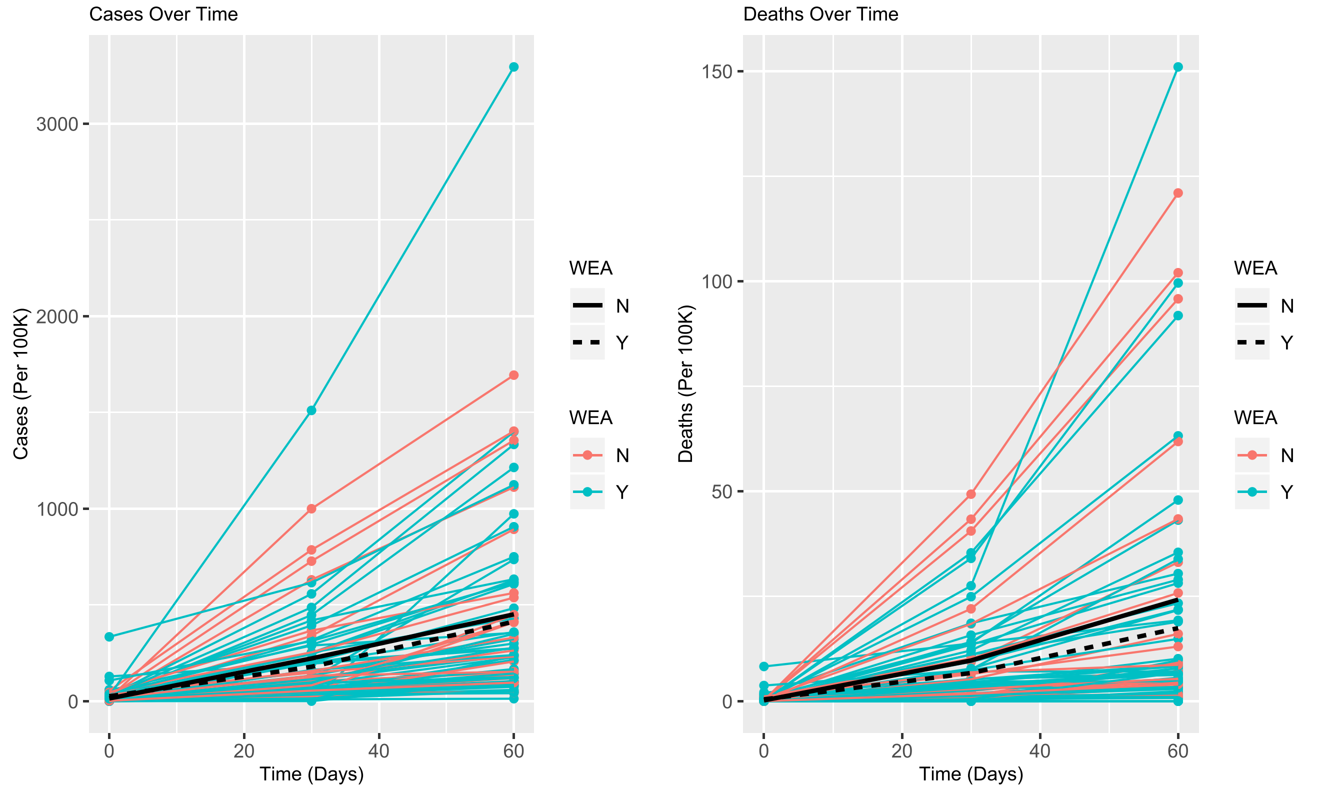

FIGURE 9 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for counties that issued WEAs and states that did not. Red and green lines are individual counties or states. Black lines are the observed means (from Table 7) [Color figure can be viewed at wileyonlinelibrary.com]

message issuance than the 24 states that issued no WEA messages (Q5).

7 | COMPARING COVID-19 WEA MESSAGES WITH BEST PRACTICE FOR 'COMPLETENESS'

We analysed the Covid-19 WEA messages to assess their level of 'completeness' vis-à-vis short warning message best practice. To repeat, Doermann et al. (2020) developed a message writing tool that ensured the inclusion of five essential categories: message source, hazard identification, hazard location, timeframe, and guidance. Importantly, FEMA's March 2020 'tip' contained three sample 90-character and two sample 360-character WEA messages, none of which exemplified a complete warning message (see supplementary Appendix A). Of the 213 messages we analysed (all of the messages included in the FEMA spreadsheet), 114 messages included the source of the message sender, 143 included the name or description of the hazard (Covid-19), 116 identified the location of the hazard (i.e., who is at risk), 92 specified a timeframe within which protective action needed to begin and/or end, and 190 messages included protective action guidance. Additionally, 112 messages included an 'embedded reference' (a hyperlink for additional information) or a 'reference number' (a phone number to call or text for additional information). Several messages were "healthcare professionals needed" requests, one was alerting the county that the courthouse's procedures were changing (appointment only), one was a warning about disinformation, and two were blank in the FEMA spreadsheet. Table 11 provides a summary of WEA message completeness.

Only five WEA messages (less than 3%) can be considered 'complete' in the way that Doermann et al. (2020) specify. The complete messages are included in supplementary Appendix A. The authors did not assess the completeness of embedded reference content. In two cases, no reference link was included, but message recipients were instructed to refer to specific websites. While there is uncertainty regarding needed levels of completeness within WEA messages themselves versus within reference link content (National Academies of Sciences Engineering and Medicine, 2018), we agree with Doermann et al. (2020) that complete WEA messages can potentially reduce milling behaviour, that is, searching for additional and confirming information.

Most Covid-19 WEA messages issued in March and April 2020 did not conform to social science best practice for short warning messages. The vast majority of Covid-19 WEA messages were 'incomplete', lacking one or more of the categories of source, hazard, location, time, or guidance. Prior research suggests that incomplete messages make it more difficult for recipients to understand, believe, and/or act to protect themselves or their loved ones (Wood et al., 2018). However, we agree with Doermann et al. (2020) that while

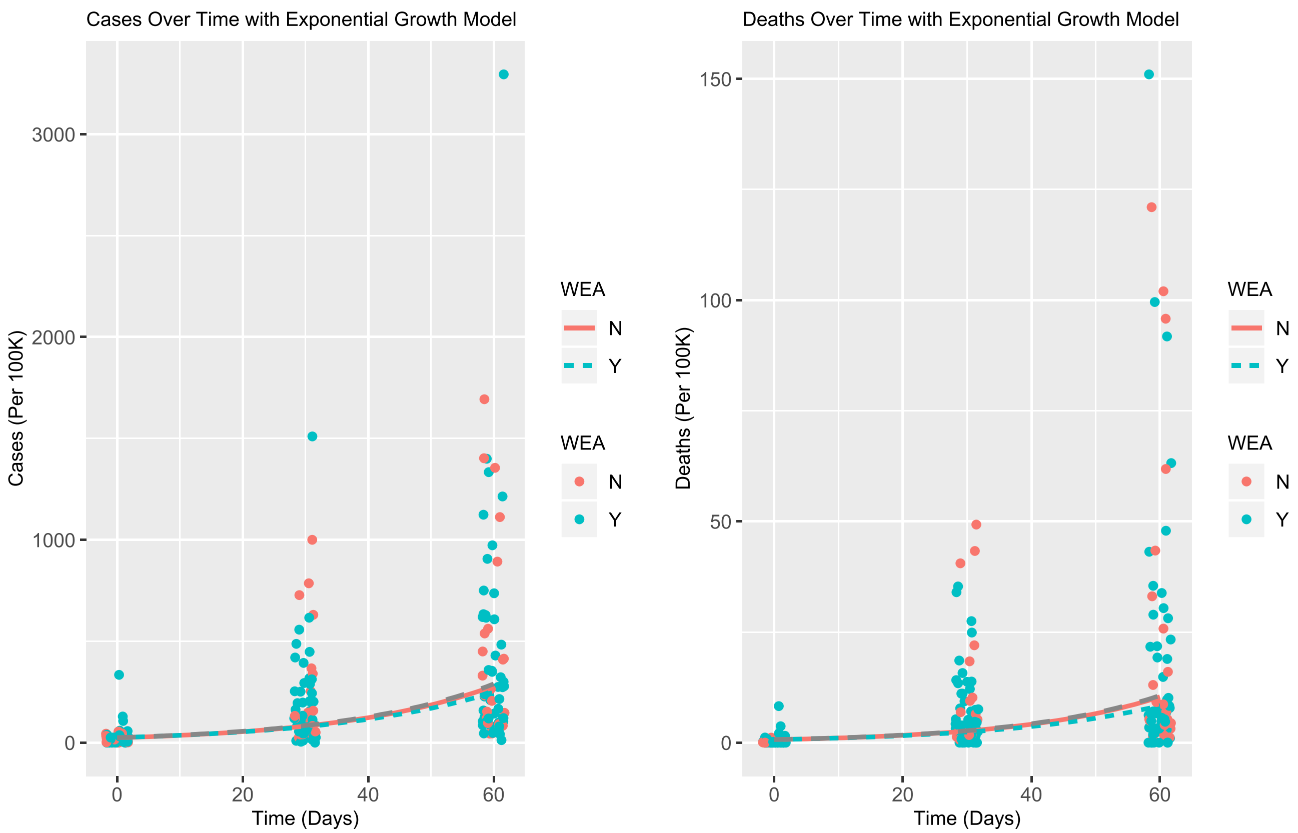

FIGURE 10 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of WEAs for counties that issued WEAs and states that did not. Red and green points are individual counties or states. The red and green curves show the fitted exponential growth model *I*(*t*) for counties that issued WEAs and states that did not. The grey dashed curve shows the expected exponential growth trajectory for counties that issued WEAs if their transmission rates (or growth rates for deaths) had been the same as those of states that did not issue WEAs (i.e., if $\Delta\alpha$ had been 0) [Color figure can be viewed at wileyonlinelibrary.com]

'initial' WEA messages should strive for completeness, subsequent WEA messages might be able to omit various content categories and still remain effective, especially if subsequent messages are issued relatively soon after the initial message. We nevertheless urge Covid-19 WEA message writers to ensure completeness to improve understanding, reduce milling, and adhere to social science best practices.

8 | COVID-19 STATEWIDE ORDERS: SOCIAL MEDIA THEMES

Roughly 4900 responses to official announcements of states' respective Orders were associated with nine categories based on the prevalence of themes found within the social media responses. Responses (see supplementary Appendix B) within the *seeking clarity* category represented roughly 23% of the total social media content analysed, slightly exceeded by *unrelated* (28%), and nearly matched by *supportive* (22%). These higher totals were followed by *opposing* (15%), *calls for stricter measures* (5%), *calls for government financial support* (2%), *doubting the efficacy of the order* (3%), *critical of the government's late response* (2%), and *hysteria* (0.4%).

Using Maryland's 30 March 2020 Order posted to Twitter as an example, statements *seeking clarity* included, 'How long is this effective for?' *Unrelated* statements included, '#illegalseizure #MedicalKidnapping of #ZenandZion by Rachel Thierry BCDSS Social Worker falsified court docs'. *Supportive* statements included, 'Thank you for listening! You'll be saving lives with your actions'. *Opposing* statements included, 'You know this violates the Constitution, right?' *Calls for stricter measures* included one user who posted an image of the WEA message and wrote, 'Why are you even allowing gatherings of 10. No gatherings should be allowed'. *Calls for government financial support* included, 'Good, now cancel rent and bills. Can't work, can't pay. Simple as that'. *Doubting the efficacy of the Order* statements included, 'It's not enough'. Statements *critical of the government's late response* included, 'About goddamn time'. Statements reflecting *hysteria* included, 'Larry Hogan was made Governor of #Maryland to aid BDSM sex crime Ring lead by Johns Hopkins Hospital'. It is worth noting that one user posted an image of the WEA message and asked, 'I live in VA [Virginia] why did I get the alert?'

Our analysis revealed that a salient category was *seeking clarity*. This category addressed three significant components of the five WEA 'completeness' elements specified by Doermann et al. (2020): location, timeframe, and guidance. The other two content

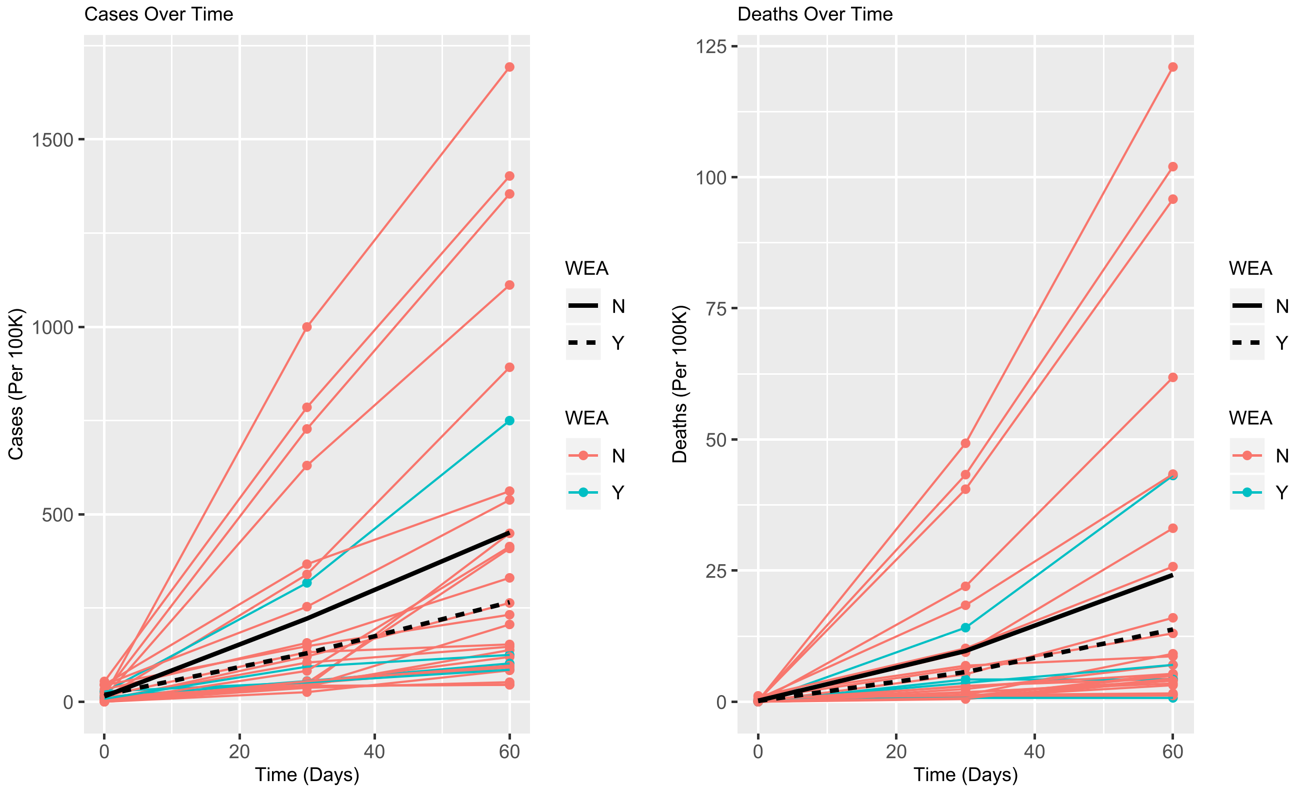

FIGURE 11 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for counties that issued 'complete' WEAs and states that did not issue WEAs. Red and green lines are individual counties or states. Black lines are the observed means (from Table 9) [Color figure can be viewed at wileyonlinelibrary.com]

elements—source and hazard—were not prominent in our analysis. The source of social media information is likely known to users because they are already 'following' official social media accounts. Similarly, the hazard—Covid-19—was already well-known and discussed largely without reference to it by name. Responses that fell into the category of *seeking clarity* largely involved questions about which businesses and activities were deemed 'essential', how long the Order would be in effect, how the Order would be enforced, and where to find the full text of the Order. Such responses illustrate the importance of using the full 360 characters permitted in a WEA message, as well as using the embedded reference function to provide additional information. Our finding herein is consistent with the bulk of prior WEA-related research that has found that short messages can spark confusion and anxiety (National Academies of Sciences Engineering and Medicine, 2018), a conclusion that contributed to the FCC's expansion of WEA messages from 90- to 360-characters. Indeed, despite Colorado's 238-character Covid-19 WEA message meeting the requirements for 'completeness' (source, guidance, hazard, location, and timeframe), as well as the inclusion of an embedded reference, roughly a third of social media responses to the Governor's Order were *seeking clarity* about what constituted an 'essential' workplace, whether children's travel between parents with joint custody was permitted, and other concerns.

Consistent with prior research (Bean et al., 2015), and despite a large percentage of *supportive* responses, the Orders also caused confusion for many recipients. Importantly, we found that there was overlap among *supportive* sentiments and responses *seeking clarity*. While many responses expressed a willingness to abide by the Governor's Order, these responses often included questions (or expressed confusion) about the lack of specific information provided. We urge WEA message writers to use the embedded reference capability of the WEA system to develop websites that anticipate such questions or rapidly respond to them.

9 | NEXT STEPS

WEA messages do not exist in a vacuum, and it is impossible for us to know what other kinds of messages the members of the communities represented in this study received. Nevertheless, our findings suggest that states and communities should not rule out using Covid-19-related WEA messages in efforts to thwart the spread of the disease. Communities will need to remain vigilant —and well-informed. WEA messages can communicate vital health information and protective action guidance, potentially inoculating recipients from dubious advice proffered via mass media channels and interpersonal networks. Covid-19-related WEA messages should strive for completeness by consistently including the content categories of source, guidance, location, hazard, and timeframe. A reference link should be included to provide additional information that specific community groups

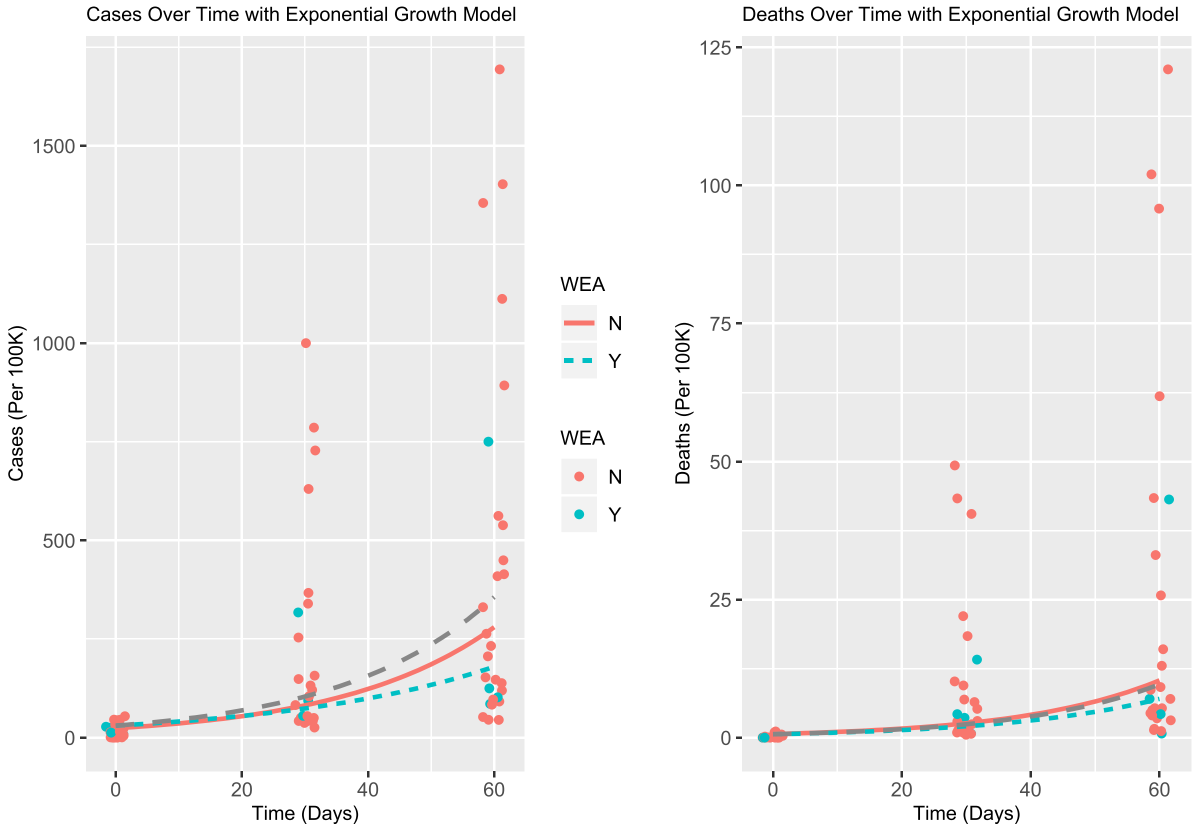

FIGURE 12 Number of cases (left) and deaths (right) per 100,000 residents at 0, 30 and 60 days after issuance of wireless emergency alerts (WEAs) for counties that issued 'complete' WEAs and states that did not issue WEAs. Red and green points are individual counties or states. The red and green curves show the fitted exponential growth model $I(t)$ for counties that issued 'complete' WEAs and states that did not issue WEAs. The grey dashed curve shows the expected exponential growth trajectory for counties that issued 'complete' WEAs if their transmission rates (or growth rates for deaths) had been the same as those of states that did not issue WEAs (i.e., if $\Delta\alpha$ had been 0) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 11 Summary of WEA message completeness

	Source	Hazard	Location	Time	Guidance	Ref. Link
Number/Percentage of WEA messages that included related content	114/54%	143/67%	116/54%	92/43%	190/89%	112/53%

may need (i.e., parents with joint custody of children, definitions of 'essential', Order enforcement mechanisms, etc.).

We may never know what influence a nationwide presidential alert WEA message that included similar guidance may have had in notifying all U.S. communities to prepare for and respond to the spread of Covid-19. The day that the U.S. national emergency was declared, 13 March 2020, might have been an opportune moment to issue a nationwide WEA message (disseminated at different times to avoid network overload) that included an embedded reference hyperlink to current health guidance. Bean (2019) has urged officials to rename the WEA system's 'presidential alert' function as 'national alert', advice that the FCC followed in 2021. In America's highly polarized political environment, whether at the national, state, or local level, officials should issue Covid-19-related WEA messages from nonpartisan sources (i.e., health officials and emergency managers).

This study's findings have implications for other types of disasters and future research. First, WEA messages are not a panacea, as some communities lack access to mobile technology. For example, according to the Pew Research Center, 87% of Hispanics born in the United States own a smartphone, compared with 69% of Hispanics born abroad (Perrin & Turner, 2019). More public attention to mobile technology inequities is needed. As sociotechnological changes unfold, we must consider that some people will continue to neither own nor have access to mobile technology, which creates profound and unacceptable inequalities in terms of safety and security. Likewise, we must also consider how differences in the capabilities of mobile devices (e.g., display settings) and wireless networks (e.g., connectivity) can create similar inequalities (Bennett & LaForce, 2019). The potential usefulness of mobile technology in combatting Covid-19 transmission indicates that these issues should not be ignored.

Second, studies of WEA message efficacy are exceedingly rare. As the use of the WEA system expands, health and safety outcome comparisons among groups of people who did and did not receive WEA messages should be conducted. Demonstrating the efficacy of WEA messages across hazards is an important evolution in understanding how to maximize the benefits of mobile technology (National Academies of Sciences Engineering and Medicine, 2018). However, to repeat, WEA messages do not exist in a vacuum, so parsing out their unique influence within a given communication ecology will be extremely difficult.

Third, WEA messages for all types of hazards and disasters should strive for completeness to reduce milling behaviour among message recipients (Wood et al., 2018). Importantly, this study found that 'seeking clarity' was a salient social media theme in response to statewide Orders issued via the WEA system; yet, the embedded reference hyperlink capability of WEA messages was underused. Roughly 50% of the messages analysed contained them. Embedded reference inclusion in every message would allow officials to offer (or reinforce) instructional guidance and rapidly provide communities updated information. Of course, hazard type influences the kinds of information that can be included in an embedded reference, but officials should not rule out using this affordance of the WEA system.

Finally, there are other factors not explored in this study that may help account for its findings. This study was limited by small sample sizes. The difficulty of determining effect sizes within different geographical areas experiencing different rates of spread, case reporting, and deaths is clear. We did not assess the influence of repeated WEA issuance, and repetition could have affected compliance with a statewide order or protective action guidance. We also did not have access to mobility data, which might have shown whether WEA issuance correlated with reductions in people's movements (see Fowler, 2020). It may be impossible to delimit a causal, law-like relationship between WEA message issuance and Covid-19 outcomes. Nevertheless, the evidence presented herein suggests that a positive effect cannot be ruled out. Complete WEA messages appear to be correlated with better health outcomes in the communities that issued them, but much more evidence is needed to rule out other factors or mere coincidence. Despite this uncertainty, social media responses reveal that many users sought clarity about the meaning or implications of statewide Orders delivered via the WEA system, which bolsters prior research that has warned of the insufficiency of short WEA messages (Bean et al., 2015; Wood et al., 2018). To help identify more factors that might explain, support, or challenge our findings, we urge researchers to conduct similar and expanded studies as more communities (both in the United States and internationally) issue WEA, WEA-like, or SMS messages in response to the Covid-19 pandemic.

DATA AVAILABILITY STATEMENT

All data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request: FEMA Covid-19 WEA message spreadsheet; statistical models in R, and message completeness tabulations.

REFERENCES

Asmelash, L., & Toropin, K. (2020, October 30). Utah sent every phone in the state an emergency alert warning about rapidly rising Covid-19 cases and overwhelmed hospitals. *CNN*. https://www.cnn.com/2020/10/30/us/utah-emergency-alert-covid-19-trnd/index.html

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bean, H. (2019). *Mobile technology and the transformation of public alert and warning*. Praeger Security International.

Bean, H., Liu, B. F., Madden, S., Sutton, J., Wood, M. M., & Mileti, D. S. (2016). Disaster warnings in your pocket: How audiences interpret mobile alerts for an unfamiliar hazard. *Journal of Contingencies and Crisis Management*, *23*(3), 141–142. https://doi.org/10.1111/1468-5973.12108

Bean, H., Sutton, J., Liu, B. F., Madden, S., Wood, M. M., & Mileti, D. S. (2015). The study of mobile public warning messages: A research review and agenda. *Review of Communication*, *15*(1), 60–80. https://doi.org/10.1080/15358593.2015.1014402

Bennett, D., & LaForce, S. (2019). Text-to-action: Understanding the interaction between accessibility of Wireless Emergency Alerts and behavioral response, *Risk Communication and Community Resilience* (pp. 9–26). Routledge.

Bertozzi, A. L., Franco, E., Mohler, G., Short, M. B., & Sledge, D. (2020). The challenges of modeling and forecasting the spread of COVID-19. Proceedings of the National Academy of Science (PNAS), *117*(29), 16733. https://doi.org/10.1073/pnas.2006520117

Casteel, M. A., & Downing, J. R. (2016). Assessing risk following a wireless emergency alert: Are 90 characters enough? *Journal of Homeland Security and Emergency Management*, *13*(1), 95–112. https://doi.org/10.1515/jhsem-2015-0024

Chen, C.-M. (2020). Public health messages about COVID-19 prevention in multilingual Taiwan. *Multilingua*, *39*(5), 597–606. https://doi.org/10.1515/multi-2020-0092

Doermann, J. L., Kuligowski, E. D., & Milke, J. (2020). From social science research to engineering practice: Development of a short message creation tool for wildfire emergencies. *Fire Technology*, *57*, 1–23. https://doi.org/10.1007/s10694-020-01008-7

Drabek, T. E. (1986). *Human system responses to disaster: An inventory of sociological findings*. Springer.

FCC. (2020a). Wireless emergency alerts. https://www.fcc.gov/consumers/guides/wireless-emergency-alerts-wea

FCC. (2020b). Public notice: Enhanced wireless emergency alerts available for coronavirus pandemic. https://www.fcc.gov/document/enhanced-wireless-emergency-alerts-available-coronavirus-pandemic

Foss, S. K. (2017). *Rhetorical criticism: Exploration and practice*. Waveland Press.

Fowler, G. A. (2020, March 24). Smartphone data reveal which Americans are social distancing (and not). *Washington Post*. https://www.washingtonpost.com/technology/2020/03/24/social-distancing-maps-cellphone-location/

Gold, H. (2020, March 27). How governments are using text alerts to fight the coronavirus pandemic. *CNN Business*. https://www.cnn.com/2020/03/27/tech/text-alert-coronavirus/index.html

Gurman, T. A., Rubin, S. E., & Roess, A. A. (2012). Effectiveness of mHealth behavior change communication interventions in developing countries: A systematic review of the literature. *Journal of Health Communication*, *17*(Suppl 1), 82–104. https://doi.org/10.1080/10810730.2011.649160

Kim, G., Martel, A., Eisenman, D., Prelip, M., Arevian, A., Johnson, K. L., & Glik, D. (2019). Wireless emergency alert messages: Influences on protective action behaviour. *Journal of Contingencies and Crisis Management*, *27*(4), 374–386. https://doi.org/10.1111/1468-5973.12278

Klein, A., & Rosenberg, E. (2020, October 20). *Mass. using new tool in COVID fight: Phone alerts for high-risk communities*. NBC 10 Boston.

https://www.nbcboston.com/news/coronavirus/mass-using-new-tool-in-covid-fight-phone-alerts-for-high-risk-communities/2214504/

Kuligowski, E. D., & Doermann, J. (2018). *A review of public response to short message alerts under imminent threat*. US Department of Commerce, National Institute of Standards and Technology. https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1982.pdf

Lindell, M. K., & Perry, R. W. (2012). The protective action decision model: Theoretical modifications and additional evidence. *Risk Analysis*, *32*(4), 616–632. https://doi.org/10.1111/j.1539-6924.2011.01647.x

Liu, B. F., Wood, M. M., Egnoto, M., Bean, H., Sutton, J., Mileti, D., & Madden, S. (2017). Is a picture worth a thousand words? The effects of maps and warning messages on how publics respond to disaster information. *Public Relations Review*, *43*(3), 493–506. https://doi.org/10.1016/j.pubrev.2017.04.004

Majeed, Z. (2020, March 25). *COVID-19: New Zealand sends emergency alert to citizens, says 'We Are Depending On You.'* Republic World. https://www.republicworld.com/world-news/rest-of-the-world-news/new-zealand-sends-emergency-alert-on-phones.html

Matthews, A. (2020, August 6). *Coronavirus: 5 things New Zealand got right*. DW. https://www.dw.com/en/jacinda-ardern-leadership-in-coronavirus-response/a-53733397

Mileti, D. S., & Sorensen, J. H. (1990). *Communication of emergency public warnings: A social science perspective and state-of-the-art assessment*. Oak Ridge National Laboratory Rep. ORNL-6609. http://www.cires.org.mx/docs_info/CIRES_003.pdf

National Academies of Sciences, Engineering, and Medicine. (2018). *Emergency alert and warning systems: Current knowledge and future research directions*. The National Academies Press.

Perrin, A., & Turner, E. (2019, August 20). *Smartphones help Blacks, Hispanics bridge some—but not all—digital gaps with whites*. Pew Research Center. https://www.pewresearch.org/fact-tank/2019/08/20/smartphones-help-blacks-hispanics-bridge-some-but-not-all-digital-gaps-with-whites/

Ripberger, J. T., Krocak, M. J., Wehde, W. W., Allan, J. N., Silva, C., & Jenkins-Smith, H. (2019). Measuring tornado warning reception, comprehension, and response in the United States. *Weather, Climate, and Society*, *11*(4), 863–880. https://doi.org/10.1175/WCAS-D-19-0015.1

Stillman, D. (2020, March 23). My cellphone should have buzzed with a coronavirus emergency alert. *Washington Post*. https://www.washingtonpost.com/weather/2020/03/23/wireless-emergency-alerts-coronavirus/

Sutton, J., Gibson, C. B., Phillips, N. E., Spiro, E. S., League, C., & Johnson, B. (2015). A cross-hazard analysis of terse message retransmission on Twitter. *Proceedings of the National Academy of Sciences*, *112*(48), 14793–14798. https://doi.org/10.1073/pnas.1508916112

Sutton, J., & Kuligowski, E. D. (2019). Alerts and warnings on short messaging channels: Guidance from an expert panel process. *Natural Hazards Review*, *20*(2), 04019002. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000324

Sutton, J., League, C., Sellnow, T. L., & Sellnow, D. D. (2015). Terse messaging and public health in the midst of natural disasters: The case of the Boulder floods. *Health Communication*, *30*(2), 135–143. https://doi.org/10.1080/10410236.2014.974124

Sutton, J., Vos, S. C., Wood, M. M., & Turner, M. (2018). Designing effective tsunami messages: Examining the role of short messages and fear in warning response. *Weather, Climate, and Society*, *10*(1), 75–87. https://doi.org/10.1175/WCAS-D-17-0032.1

Tracy, S. J. (2013). *Qualitative research methods: Collecting evidence, crafting analysis, communicating impact*. John Wiley & Sons.

Wood, M. M., Mileti, D. S., Bean, H., Liu, B. F., Sutton, J., & Madden, S. (2018). Milling and public warnings. *Environment and Behavior*, *50*(5), 535–566. https://doi.org/10.1177/0013916517709561

World Health Organization. (2011). *mHealth: New horizons for health through mobile technologies* (Vol. 2011, p. 6). World Health Organization.

World Health Organization. (2020). Covid-19 SMS message library. https://www.who.int/publications/i/item/covid-19-message-library

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Bean, H., Grevstad, N., Meyer, A., & Koutsoukos, A. (2022). Exploring whether wireless emergency alerts can help impede the spread of Covid-19. *Journal of Contingencies and Crisis Management*, 30, 185–203. https://doi.org/10.1111/1468-5973.12376