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Communicating infectious disease prevalence through graphics: Results from an international survey

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ABSTRACT

Background: Graphics are increasingly used to represent the spread of infectious diseases (e.g., influenza, Zika, Ebola); however, the impact of using graphics to adequately inform the general population is unknown.
Objective: To examine whether three ways of visually presenting data (heat map, dot map, or picto-trendline)—all depicting the same information regarding the spread of a hypothetical outbreak of influenza—influence intent to vaccinate, risk perception, and knowledge.
Design: Survey with participants randomized to receive a simulated news article accompanied by one of the three graphics that communicated prevalence of influenza and number of influenza-related deaths.
Setting: International online survey.
Participants: 16,510 adults living in 11 countries selected using stratified random sampling based on age and gender.
Measurements: After reading the article and viewing the presented graphic, participants completed a survey that measured interest in vaccination, perceived risk of contracting disease, knowledge gained, interest in additional information about the disease, and perception of the graphic.
Results: Heat maps and picto-trendlines were evaluated more positively than dot maps. Heat maps were more effective than picto-trendlines and no different from dot maps at increasing interest in vaccination, perceived risk of contracting disease, and interest in additional information about the disease. Heat maps and picto-trendlines were more successful at conveying knowledge than dot maps. Overall, heat maps were the only graphic to be superior in every outcome.
Limitations: Results are based on a hypothetical scenario.
Conclusion: Heat maps are a viable option to promote interest in and concern about infectious diseases.

1. Introduction

Outbreaks such as the severe acute respiratory syndrome (SARS), H1N1 influenza, the Ebola virus, and the Zika virus have, at various times, seized public attention. While these diseases have affected different populations with varying severity, public knowledge of each outbreak has been spurred through multiple modalities—by traditional patient-healthcare provider relationships and also by news outlets [1,2], local health departments [3–5], international health organizations [6–8], and social media [9–11]. For instance, during the H1N1, Ebola, and Zika outbreaks, topics discussed through social media included risk factors, prevention, experience, and disease trends [12–16].

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To communicate disease prevalence and spread, visuals often matter more than words [17–19]. Graphics developed for public health purposes are widely disseminated through social media [20,21]. Much like the spread of a disease, outbreak-related graphics and videos inspire a cascade of additional tweets and Internet searches [20,22]. Therefore, the effect different visualization strategies have on the general public is particularly relevant to public health experts.

Yet, it remains unclear which types of graphics are most informative, preferred, and appropriate for the dissemination of public health information. On one hand, graphics are often able to circumvent problems with literacy and numeracy that may be encountered when attempting to communicate risk [23]. The use of graphics has repeatedly been demonstrated to improve patient understanding, enhance decision-making, and shape risk perception [24,25]. On the other hand, the design of visuals can also have a negative impact on understanding and reactions to information. For example, even accurate graphics may distract individuals from relevant statistical information [26]. In addition, while most people may prefer the graphical presentation of data, graphics may affect perceptions of risk idiosyncratically [27–29]. Yet, graphics remain a cornerstone of the broad dissemination of public health knowledge [30,31].

In this study, we focused on a critical health communication situation—how to communicate effectively to the public and to motivate preventive behaviors among those at the epicenter of an infectious disease (in this case, an influenza outbreak). We compared three ways of visually representing the same data about the spread of disease to determine which format resulted in the greatest differences in participants' knowledge, risk perceptions, or desire to receive a future vaccination. In addition, we evaluated which graphic was preferred since proclivity to view the graphic is an important component to its effectiveness. To ensure that our approach would be generalizable across populations, we tested this question in an 11-country experiment, showing participants a simulated news article in the country's primary language.

2. Methods

2.1. Study population

We recruited a stratified random sample of adults (age > 17) from a panel of Internet users administered by Survey Sampling International (SSI), which recruits panel members through various opt-in methods, including website banners, television advertisements, e-mails, apps, social media, and websites. SSI employs a probability-weighted random process to select panel members. For our study, quotas were established based on respondent age and gender to ensure that the sample was representative for each country. The sampling algorithm continued to recruit SSI participants until all quotas were achieved. Participants were recruited between February and March 2016. Incomplete surveys were excluded. Upon survey completion, participants were entered into drawings administered by SSI for modest prizes.

Subjects were recruited from the following countries: Finland, Germany, Hungary, Italy, the Netherlands, Norway, Poland, Spain, Sweden, the United Kingdom, and the United States and received surveys in the primary language of the country in which they resided.

2.2. Survey

Participants were asked to imagine an outbreak of influenza and then provided with a simulated news article that described the spread of influenza in their respective country. The article contained information regarding the influenza virus, its potential symptoms, and a vaccine being developed (Appendix). Articles were translated from English to the predominant language of the country. Articles were cross-randomized to provide participants with five varying communication strategies, such as symptom severity, confidence portrayed by a scientific expert, name used for the influenza strain, the use of metaphors to describe the spread of influenza, and type of graphic used to communicate prevalence of and deaths due to influenza. As none of these other communication strategies interacted with the type of graphic used to communicate prevalence, those results are not included.

This study focused on the use of three graphics: dot map, heat map, picto-trendline (Fig. 1). Dot maps, also known as dot density maps, use different sized circles on a map to represent differences in disease prevalence and to demonstrate a spatial pattern [32,33]. Dot maps have been widely used in infectious disease communication by leading health organizations (e.g., the WHO and the CDC used dot and heat maps during the Ebola outbreak [30,31]). Heat maps are displays that illustrate changes in disease prevalence by using color overlays for different regions. Using colors has been demonstrated to effectively illustrate uncertainty and variation in probability [34]. Picto-trendlines are a variant of pictographs, or icon-based displays of probabilities, that use lines to represent numbers of people affected [35].

All participants received information in the graphics representing an increase in prevalence of influenza and number of influenza-related deaths over a three-month span of time. Prevalence of influenza and deaths due to influenza were derived from actual rates documented from the 2009 H1N1 influenza outbreak and were then extrapolated to each country based on its population. While the picto-trendline graphic only showed country-specific data, both the dot map and heat map graphics displayed country-specific data relative to all European countries. The participant's country of origin always had the highest disease prevalence in comparison to other European countries, and case counts decreased as geographical distance increased. For example, German participants received a graphic with Germany having the highest prevalence of influenza and deaths due to influenza, followed by slightly lower rates in surrounding countries (i.e., Poland, the Netherlands, Czech Republic), and the lowest prevalence of influenza and deaths related to influenza in the countries farthest away (i.e., Spain, Ireland, Greece). Each graphic contained a legend to help orient participants to the information. All graphics were created using Adobe Illustrator and Microsoft Paint.

2.3. Data quality

All Survey Sampling International (SSI) participants undergo systematic quality controls prior to inclusion in any sample. For example, SSI uses digital fingerprinting to flag duplicate respondents. SSI performs continuous monitoring to assess for inappropriately quick responses or inattention. To confirm location, SSI uses two-factor authentication prior to reward redemption [36].

2.4. Outcomes

After reading the newspaper article, participants completed a survey that measured perceived likelihood of contracting influenza [defined by a discrete visual analog scale ranging from 1 ("Very unlikely") to 7 ("Very likely")], vaccination interest [defined by a discrete visual analog scale ranging from 1 ("Definitely would not get a vaccination") to 7 ("Definitely would get a vaccination")], interest in additional information about influenza [defined by a discrete visual analog scale ranging from 1 ("not at all") to 7 ("a great deal")], knowledge about information contained in the news article (percentage of two questions answered correctly about

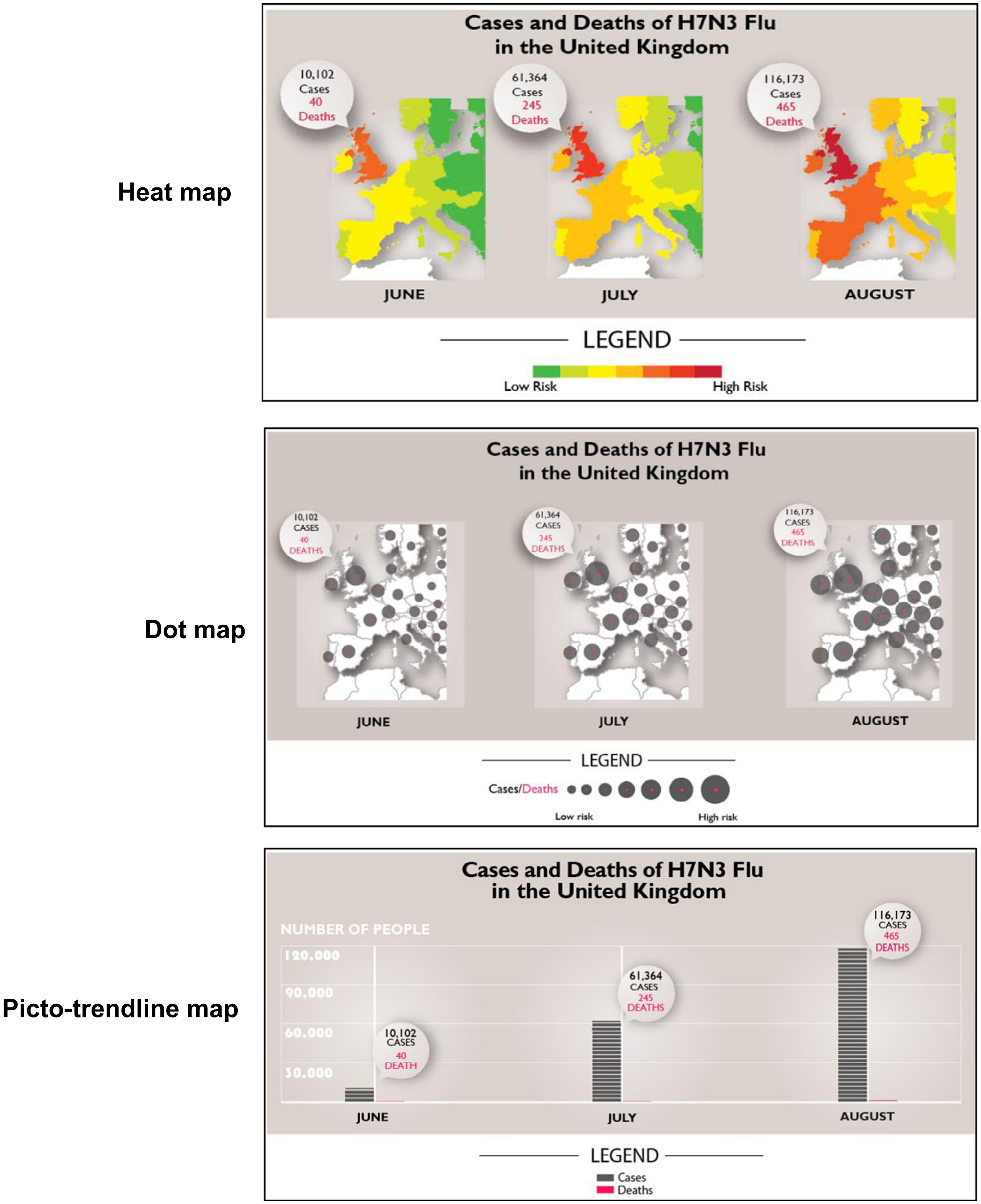

Fig. 1. Example of graphics provided to UK participants.

information presented in the graphic), graphic preference (aggregate measure of five items—perceived efficacy, helpfulness, science, interpretability, and trustworthiness of the graphic), and standard demographics (e.g., age, gender, education).

2.5. Statistical analysis

Chi-square tests were used to evaluate associations between the graphic received and respondent characteristics. Analysis of variance testing with Bonferroni correction was performed with each outcome as the dependent variable and the presented graphic as the independent variable. While there is controversy as to whether Likert-type data should be analyzed as continuous, ordinal, or dichotomous, the work of Norman and others has demonstrated ANOVA to be robust to non-parametric data [37].

To evaluate moderation effects, two-way analysis of variance testing was performed on each outcome as the dependent variable and the presented graphic as one independent variable and either recent vaccination history, country, and gender as the second independent variable. For age and education, analysis of covariance was used. All analyses were conducted using Stata 14.1 (College Station, TX).

The University of Michigan Medical Institutional Review Board deemed this study exempt from review.

2.6. Role of the funding source

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3. Results

In total, 20,138 individuals started the survey. Of those who started, 16,510 individuals from 11 countries completed the survey (82% completion rate). Respondents took a median of 18 min (inter-quartile range 13–25 min) to complete the survey. Respondents were recruited from the following countries: Finland (n = 1554), Germany (n = 1546), Hungary (n = 998), Italy (n = 1509), the Netherlands (n = 1938), Norway (n = 764), Poland (n = 1509), Spain (n = 1604), Sweden (n = 1539), the United Kingdom (n = 1762), and the United States (n = 1787).

Among the respondents, the average age was 46.8 years (SD 16.2). Females comprised 49.8% of the respondents. The majority of respondents were married (60.7%). About 9.1% of respondents were healthcare workers, and 4999 (30.5%) respondents had received an influenza vaccination within the past two years (Table 1).

After reading the simulated newspaper article, respondents indicated that they preferred heat maps and picto-trendlines versus dot maps (4.90 vs. 4.93 vs. 4.40, $P < 0.001$) (Fig. 2, Table 2, and Appendix Table 1). Additionally, respondents who received the heat map were significantly more likely to be interested in vaccination (4.67 vs. 4.56, $P = 0.01$), perceive a greater likelihood of contracting influenza (3.62 vs. 3.50, $P < 0.001$), and be interested in more information about influenza (5.27 vs. 5.20, $P = 0.04$) compared to those who received a picto-trendline. Overall, knowledge obtained from graphics was low; however, respondents who received heat maps (25.4%) and picto-trendlines (25.4%) were significantly more likely to answer knowledge questions correctly than those who received dot maps (22.7%) ($P < 0.001$). Respondents who received the dot map reported a significantly higher perceived likelihood of contracting influenza (3.58 vs. 3.50, $P = 0.03$) than those who received a picto-trendline, but dot maps did not differ significantly from heat maps or picto-trendlines for all other outcomes (all $P > 0.06$) (Table 2 and Appendix Table 1).

For the outcome of graphic preference, there was an interaction between the graphic received and country of the respondent ($P < 0.001$). This moderating effect was due to differences in whether heat maps or picto-trendlines were rated higher than the other; dot maps were preferred least in all countries (Fig. 2). However, graphic preference was not moderated by recent vaccination history, education, age, country, or gender (all $P > 0.10$).

4. Discussion

In an international survey, we demonstrated that communicating disease prevalence through heat maps and picto-trendlines were preferred over dot maps. However, heat maps increased interest in vaccination, perceived risk of contracting influenza, and desire for additional information about influenza compared to picto-trendlines.

Data visualization has increased the popularity of alternative methods to presenting statistical information. For instance, projects such as Gapminder [38] have developed animations of world income distribution and global health that are easy to understand. However, to our knowledge, this work is the first to experimentally evaluate visualization strategies to communicate infectious disease prevalence to the general public. Numerous studies have evaluated the impact of graphics on risk communication [24,25].

Table 1
Respondent characteristics by graphic received.

	Type of graphic received			All respondents
	Heat map	Dot map	Picto-trendline	
Respondents	5553 (33.6)	5476 (33.2)	5481 (33.2)	16,510
Age				
<35	1500 (27.6)	1451 (27.0)	1483 (27.6)	4434 (27.4)
35–50	1436 (26.4)	1419 (26.4)	1370 (25.5)	4225 (26.1)
50–59	860 (15.9)	869 (16.2)	898 (16.7)	2630 (16.3)
60+	1639 (30.1)	1632 (30.4)	1625 (30.2)	4896 (30.3)
Gender				
Male	2774 (50.2)	2687 (49.4)	2648 (48.6)	8109 (49.4)
Female	2715 (49.2)	2700 (49.6)	2754 (50.6)	8169 (49.8)
Other	33 (0.6)	52 (1.0)	43 (0.8)	128 (0.8)
Married	3364 (60.9)	3297 (60.5)	3316 (60.8)	9977 (60.7)
Healthcare worker	518 (9.4)	479 (8.9)	481 (8.9)	1478 (9.1)
Vaccinated within past 2 years	1705 (30.9)	1666 (30.6)	1628 (29.9)	4999 (30.5)
Region				
Finland	535 (9.6)	513 (9.4)	506 (9.2)	1554 (9.4)
Germany	512 (9.2)	509 (9.3)	525 (9.6)	1546 (9.4)
Hungary	348 (6.3)	327 (6.0)	323 (5.9)	998 (6.0)
Italy	505 (9.1)	509 (9.3)	495 (9.0)	1509 (9.1)
The Netherlands	647 (11.7)	624 (11.4)	667 (12.2)	1938 (11.7)
Norway	259 (4.7)	258 (4.7)	247 (4.5)	764 (4.6)
Poland	500 (9.0)	509 (9.3)	500 (9.1)	1509 (9.1)
Spain	532 (9.6)	532 (9.7)	540 (9.9)	1604 (9.7)
Sweden	507 (9.1)	518 (9.5)	514 (9.4)	1539 (9.3)
United Kingdom	597 (10.8)	592 (10.8)	573 (10.5)	1762 (10.7)
United States	611 (11.0)	585 (10.7)	591 (10.8)	1787 (10.8)

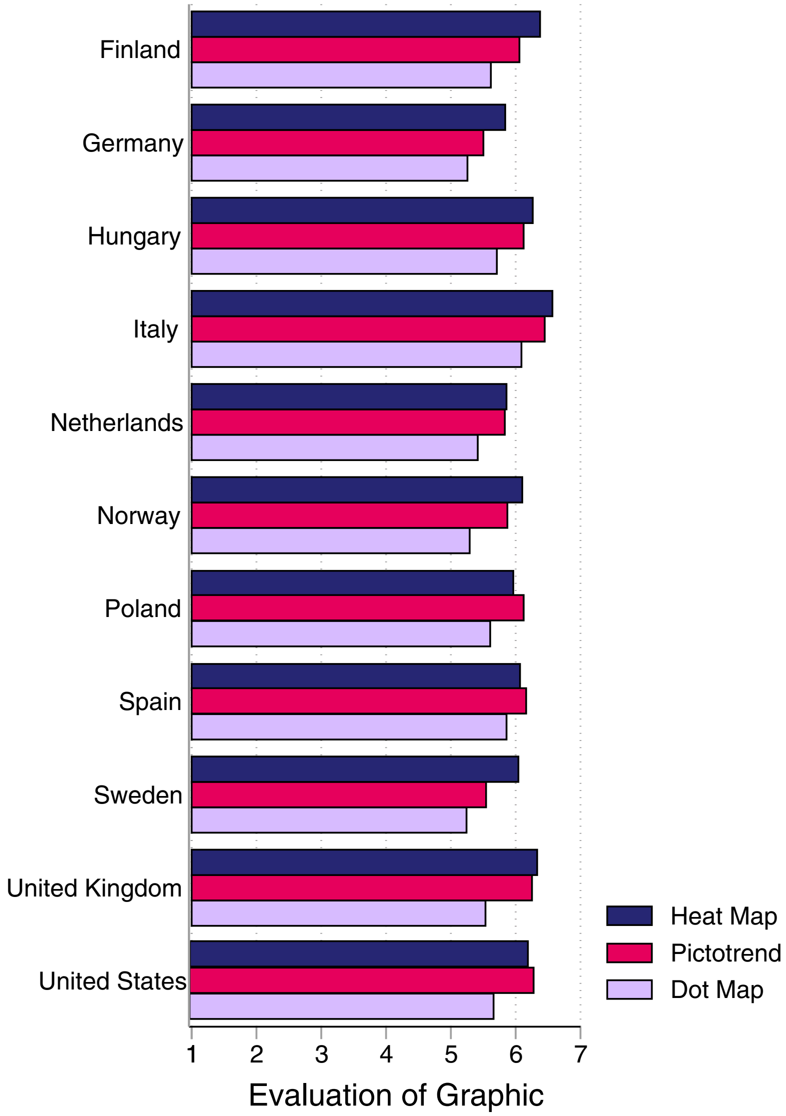

Fig. 2. Graphic preferences by country.

Table 2
Association between graphics and outcomes.

Measure	Heat map[*]	Picto-trendline	Dot map	F test	*P* value
Evaluation of graphic	4.90 (1.32)[+]	4.93 (1.37)[+]	4.40 (1.42)	258.66	<0.001
Vaccination intention	4.67 (2.00)[#]	4.56 (2.03)	4.64 (2.02)	4.37	0.01
Perceived likelihood of contracting influenza	3.62 (1.64)[#]	3.50 (1.62)[+]	3.58 (1.64)	7.55	<0.001
Interested in more information	5.28 (1.70)[#]	5.20 (1.74)	5.27 (1.71)	3.88	0.02
Knowledge (% correct)	25.4% (32.9)[+]	25.4% (33.7)[+]	22.7% (32.0)	11.63	<0.001

[*] Mean (SD).
[+] $P < 0.05$ vs. Dot Map.
[#] $P < 0.05$ vs. Picto-trendline Map.

However, this prior work has primarily focused on communicating to individual patients—particularly the risks and benefits individuals would receive as a result of a medical procedure. While epidemiologists have long used graphical displays to illustrate the spread of disease [39,40], that work has focused on delivering information to highly trained public health specialists. In contrast, this study assesses graphics that communicate disease prevalence to the general population, simulating that their country is at the epicenter of an infectious disease outbreak. This type of communication is especially relevant to public health and government officials seeking to provide broadly accessible health information. As the lay public receives more of its health information multidimensionally, from healthcare experts, news, and social media, it is critically important to evaluate the most appropriate graphics used to communicate disease prevalence, spread, and risk.

Understanding optimal communication strategies is of particular importance in relation to influenza, where vaccination greatly reduces the risk of contracting disease [41,42]; yet, vaccination rates remain suboptimal [43]. Prior research related to public health communication and influenza has demonstrated that the general public prefers brief, balanced, and evidence-based messages [44–46]. However, there is currently no standard method for the graphical communication of epidemiological data to the lay public. The WHO and the CDC used a combination of dot and heat maps during the recent Ebola outbreak to depict prevalence [30,31]. Dot maps appear most often in the literature [32,47–49]. However, heat maps have been discussed infrequently in the literature. In one study of Europeans interested in weather forecasts, a color contour map featuring hypothetical forecasts was preferred over six other more typical formats of graphical presentation of data, such as bar graphs, pie charts, and line graphs [50]. Yet, we found that while both heat maps and picto-trendlines were preferred over dot maps, the use of heat maps to demonstrate the spread of disease increased interest in vaccination compared to the use of picto-trendlines and no differently than dot maps. Furthermore, dot maps appeared to be the worst method to convey information, as respondents with dot maps had less knowledge gained from the graphic compared to those with heat maps and picto-trendlines. Thus, unlike dot maps and picto-trendlines, heat maps achieved the trifecta—greater respondent preference, increased interest in vaccination, and better translation of knowledge.

Graphics must also be carefully examined to assess both their potential positive and negative impact. Visuals can produce a wide variety of emotional responses that may be difficult to predict [23,27]. Furthermore, it is often difficult to adequately illustrate uncertainty in risk communication [51]; however, this becomes even more imperative when presenting graphics at the population level, since risk may vary greatly between individuals and across locations. Experimental evidence remains limited as to how different graphics are processed and understood [51]; therefore, additional research is necessary to evaluate the impact of public health graphics aimed at the general population. In particular, it is unclear how other modes of communication, such as animations and videos, impact public health communication. Our prior work using animation in the context of cancer treatment options suggests that animated graphics may result in suboptimal risk communication [52].

This study must be interpreted in the context of several limitations. First, we chose three graphics to present to participants, but other graphics not presented in this study could be better suited to communicate disease prevalence. However, these graphics were chosen based on a pilot study in which these three graphics were the most promising. In addition, this study used graphics to accompany text, which may have a different effect than graphics viewed in isolation. Second, each respondent viewed a single graphic; however, no single graphic may suit the communication needs of all individuals. Furthermore, in this study, the picto-trendline graphic contained data only on the participant's country, compared to heat maps and dot maps, which included data on surrounding countries. However, including additional data in the picto-trendline graphic may increase its complexity and decrease its efficacy. Third, while differences seen in this study were statistically significant, it is difficult to project whether they are clinically relevant. Fourth, preferences in this study were developed based on a hypothetical scenario, which may not correspond with preferences during an actual pandemic of influenza. For example, we examined interest in future vaccination, which may not be perfectly correlated with actual vaccination. However, vaccination intentions are strongly associated with subsequent vaccination [53]. Additional research is necessary to determine how these graphics affect actual vaccination rates. Finally, our study sampled participants from Europe and the United States and may not be generalizable to developing nations.

Despite these limitations, these findings have implications for public health officials, clinicians, and the general public. As health information continues to be disseminated in a multitude of channels, additional research is necessary to understand the best way to present meaningful data. Graphics have the potential to improve public health, but our research demonstrates that not all graphics are equally effective. Heat maps may provide a means to generate more widespread interest, awareness for evidence-based treatments, desire for more information, and convey relevant knowledge.

5. Conclusion

Among a large international sample, the use of heat maps to demonstrate the spread of infectious disease increased interest in vaccination, knowledge, and desire to learn more about the disease. Of the tested graphics, heat maps were the best option to increase vaccination rates and promote infectious disease awareness.

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Study concept and design: Fagerlin, Scherer, Knaus, Das, Zikmund-Fisher.

Acquisition of data: Fagerlin, Knaus.

Analysis and interpretation of data: Fagerlin, Valley, Scherer, Knaus, Das, Zikmund-Fisher.

Drafting of the manuscript: Fagerlin, Valley.

Critical revision of the manuscript for important intellectual content: Fagerlin, Valley, Scherer, Knaus, Das, Zikmund-Fisher.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2017.05.048.

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