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The Go Noroviral Experiment: An Interactive Citizen Science Teaching Tool for Modeling Norovirus Transmission

ABSTRACT

Human noroviruses are a frequent cause of foodborne illness, although they are most commonly transmitted via person-to-person contact. Here we describe a citizen science experiment performed at a large international food safety conference, where attendees participated in a mock norovirus outbreak that stemmed from one 'infected' person attending a reception. The "infection" was then visibly and physically transmitted to others, with individually numbered buttons representing the virus. The button numbers as well as other data provided by the participants were used in standard epidemiological analyses to track and measure the scope of the outbreak, which was presented for the educational benefit of the participants. A novel feature of the experimental design is that the mock outbreak evolved on the basis of the actions of the participants; therefore, each time the exercise is performed, the results would be unique. Based on successful proof of concept, this interactive tool can be used by schools, exhibitors, and other educational groups to illustrate person-to-person transmission of infectious agents and the common formats for displaying and interpreting epidemiological data.

INTRODUCTION

Human noroviruses are the most common cause of acute gastroenteritis in the United States, as well as the most common cause of foodborne illness *(8, 9, 19)*. Although these viruses can contaminate and persist on foods, on surfaces, and in water, they are most often spread by direct person-to-person contact *(8, 9)*. Transmission often occurs in places where people gather and/or share food, such as hospitals, schools, and eldercare facilities *(8)*. In such settings, the presence of a single infected individual or vomiting event can lead to a cascade of disease *(2, 14)*.

Tools used for modeling the transmission of infectious agents and/or preparedness for outbreaks are common in a risk-based public health system. Mock disease outbreak exercises have typically been reserved for emergency

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responders (diagnostic laboratory personnel, government employees, epidemiologists, etc.) as training drills, to improve response and control times in the event of actual outbreaks (for recent examples, see *16, 21*). Disease outbreak exercises for student training in health-related fields focus on information gathering and decision-making as an application of their knowledge, sometimes with added epidemiological analyses *(1, 12, 17)*.

Recently, citizen science projects, which enlist members of the public for the collection of scientific data, have become a means of educating the participants in the topic of study *(3)*. A classic example is the Great Backyard Bird Count led by the Cornell Lab of Ornithology and the National Audubon Society. Each year since 1998, members of the public have submitted checklists of birds they see; in 2016, over 162,000 checklists were submitted *(5)*. In addition to gaining this immense biological dataset, the researchers are able to measure improvements in participant knowledge, including their understanding of scientific research in general *(3)*. Two recent citizen science projects related to infectious disease have involved self-reporting of symptoms or observed outbreaks, serving both as a means of collecting large amounts of data and as a conduit for educating the participants with real-time updates on disease occurrence in their area *(4, 7)*.

In this paper, we describe the implementation of an interactive teaching tool to illustrate norovirus transmission. Its utility was demonstrated at a large international food safety conference, where attendees participated in a mock norovirus outbreak that arose from one 'infected' person attending a reception the first night of the conference. The infection was then visibly and physically transmitted to others, with individually numbered buttons representing the virus. The data were analyzed by use of both classic epidemiological methods and a novel visual network of the outbreak.

MATERIALS AND METHODS

The 'infectious' agent

Wearable buttons with a norovirus image (Busy Beaver Button Co., Chicago, IL) served as visible proxies for the virus and as symbols of infection. Five-hundred one buttons were individually numbered (0–500) and affixed to similarly numbered cards requesting the recipient to visit a specific exhibit booth (NoroCORE) to take part in the experiment.

Participants and setting

The experiment was performed during the 2015 International Association for Food Protection (IAFP) Annual Meeting in Portland, Oregon. The outbreak began with a single index case, 'Patient Zero' (recipient of button 0, a volunteer from the NoroCORE executive board), who infected ten other attendees (buttons 1–10) at a pre-meeting reception. This was a transmission scenario that could easily occur in an actual norovirus outbreak. Because there were over 3,250 attendees at the conference (personal communication with Lisa Hovey, Assistant Director of IAFP, November 10, 2015), approximately one in every seven attendees (500/3,250) could have been infected in this exercise.

Disease transmission

A person became "infected" by receiving a button from someone who was already infected. For this purpose, buttons 11 through 500 had been separated sequentially into sets of five and placed in individual plastic bags for infected individuals to distribute. An infected person could receive up to two sets of five buttons, depending on availability, from the exhibit booth to give to anyone who was not yet infected. The limit of 10 buttons served to maximize the number of potential players for the number of buttons, and also to facilitate modeling of the nature of actual person-to-person transmission based on upper-end estimates of transmissibility (R_0) for human norovirus *(11, 13)*.

As an incentive, an infected person who presented his or her button at the exhibit booth became a "confirmed" case of norovirus and was entered into two raffles for prizes. Participants entered the second raffle by explaining when and where they were infected. As further incentive for those distributing buttons, for each person he/she infected who in turn visited the exhibit booth to record his or her button number, the distributor received an extra raffle entry.

Data collection

The exhibit booth served as the hub of the outbreak investigation, and although NoroCORE staff recorded which button holders returned to the exhibit booth and who received sets of buttons, the conference participants were actually responsible for all of the disease transmission and simulation data submission during the experiment. Rule sheets were available upon request, and participants received a verbal description of the experiment and its purpose when they first came to the booth. Contact information was obtained from participants solely for the purposes of the raffle; for the experiment, participants were identified only by their button numbers, and as an educational exercise, it was exempted from the requirements of the North Carolina State University IRB.

DATA ANALYSIS

Three analyses were performed on this outbreak: an epidemic curve, the creation of a visual network of the person-to-person transmission, and the calculation of the mock virus' reproduction number, R_0. Epidemic curves are graphical representations of the time course of an outbreak and are displayed as a plot of the number of cases on the y-axis, with the time of onset of symptoms on the x-axis. Epidemic curves provide clues such as the nature of the infectious agent; its possible transmission routes; and features such as incubation period, duration, and magnitude of disease *(18)*. An epidemic curve was created using Microsoft Excel, and a transmission web of the outbreak was created using a basic two-column Microsoft Excel spreadsheet (one column for people infecting others and one column for those they infected) imported into Cytoscape 3, an open source software program for visualizing networks (Cytoscape Consortium, San Diego, CA).

Infectious diseases can also be characterized by their R_0, which is simply the average number of people a single infected person is expected to infect, assuming everyone in the population is susceptible to the disease *(10, 15)*. The R_0 represents the transmission potential of an infectious agent; the higher the R_0 relative to a benchmark of 1.0, the more extensive the expected spread of disease *(10, 15)*. Weighted averages of the number of returned buttons (corresponding to 'confirmed' cases of norovirus) were used to calculate R_0 values.

RESULTS

Response rate

All 100 bags containing five buttons each were distributed from the exhibit booth. Overall, 248 of the 500 people potentially infected during the experiment visited the NoroCORE exhibit booth (49.6% response rate), becoming "confirmed" cases of norovirus, and 198 of these people explained where and when they were infected (79.8%). The 252 other individuals who may have been infected but did not visit the booth were "suspected" cases of norovirus. Ultimately, 88 individuals were responsible for spreading the virus. However, because of unexpected enthusiasm for the experiment on the first evening of the conference and the number of buttons, restrictions had to be placed thereafter on when infected individuals could receive buttons from the exhibit booth.

Reproduction number

Excluding Patient Zero's initial ten infections (since these were automatically recorded at the start of the outbreak), the number of confirmed secondary cases arising from a single infected individual varied from 8 to 0. As 77 of the 88 participants spreading the virus could distribute only five buttons instead of ten, an adjusted weighted average of the number of buttons that returned to the booth for each bag of five buttons *(Fig. 1)* was used to estimate an R_0 of 2.48.

Location of infection

Although the vast majority (n = 166, 84%) of infections occurred in the exhibit hall, several (n = 16, 8%) occurred in the conference oral presentation rooms *(Fig. 2)*. The "Reception" area represents the ten initial infections caused by Patient Zero at the opening session reception (5%). The five "Other" (2.5%) responses were specifically "City Downtown" (n = 2), "Poster," "Lunch," and "Lobby"; some of these may have been referencing the exhibit hall, but this cannot be assumed.

Time of infection

Because the participants assigned their time of infection to one of 12 four-hour time slots, an epidemiologic curve for the mock outbreak was easily produced *(Fig. 3)*. Unexpected infection times (e.g., 12:00 a.m. – 4:00 a.m.) were confirmed with the participant when they visited the booth. Because of the high demand and limited supply, buttons were available from the booth from 7:30 p.m. to 9:30 p.m. on Saturday, July 25th, 2015, and from 10:00 a.m. to 12:00 p.m. and from 5:00 p.m. to 5:20 p.m. on Sunday, July 26th. Recording of new cases ended at 1:00 p.m. on Monday, July 27th, the last full day on which the exhibit hall was open.

Web of infection

The node-link tree displays the entirety of the outbreak and the connections between the individual participants *(Fig. 4)*. Blue dots signify infected individuals who had their button number recorded at the booth ('confirmed' cases), while gray dots represent buttons that may have been distributed but did not come back to the booth ('suspected' cases). The longest chain of confirmed cases reached eight degrees of separation from Patient Zero, and distinct branches of transmission arose from nine of the ten individuals initially infected at the opening reception.

DISCUSSION

Public reception

Anecdotal feedback volunteered by the participants was overwhelmingly positive; the attendees were perceived to be enthusiastic and curious about participating, which generated discussion about norovirus and similarly-transmitted agents. People of all ages and genders participated and were a representative cross section of IAFP membership, including individuals from academia, industry, regulatory agencies, and public health groups. Conference staff and other exhibitors were also seen wearing the buttons. When the option to infect other people was available, the majority of participants did elect to distribute buttons. However, this enthusiasm made it necessary to set restrictions on button distribution periods. During distribution times, around 100 buttons were leaving the booth per hour. This unforeseen outcome undoubtedly affected the course of the exercise, although because of the exponential nature of the outbreak, doubling or even tripling the number of available buttons may have led to a similar result.

Translating the interactive to real-world epidemiology

The exercise demonstrated the expansive nature of a norovirus outbreak and physical transmission of a pathogen. The fact that this was not a real disease outbreak and that

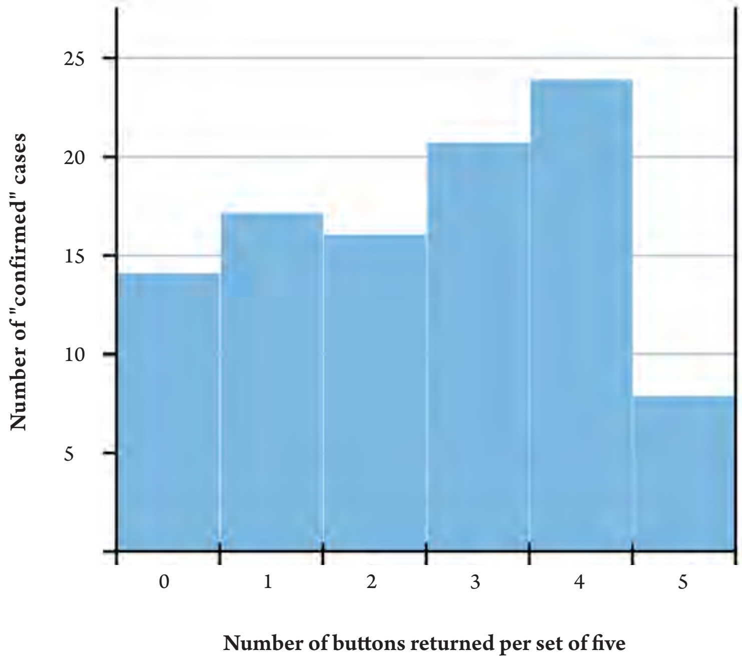

Figure 1. Distribution of the number of subjects returning to the exhibit booth (representing "confirmed" cases) from each individual set of five buttons distributed across all 100 sets of five buttons each

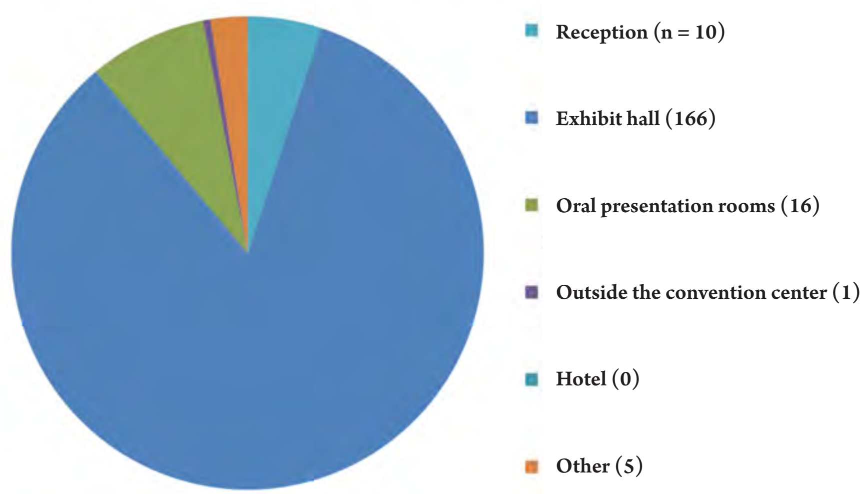

Figure 2. Locations in which subjects became "infected," based on participant responses

the number of proxy virus buttons was limited led to some constraints best seen in the data analysis. For example, a conventional epidemic curve charts onset of symptoms, while we charted time of "infection" because there were no symptoms. The curve produced from these data would have been more continuous if button distribution had not been restricted to specific times, or if people stayed active 24 hours per day. Omitting the overnight time points, we still see a predominant peak that rose sharply and then tapered off, in keeping with what is observed for a common or point-source outbreak, where a short-term exposure passes quickly through a population *(20)*. This curve shape is also common to actual norovirus outbreaks *(20)*. An additional overarching constraint, also present in actual outbreaks, is

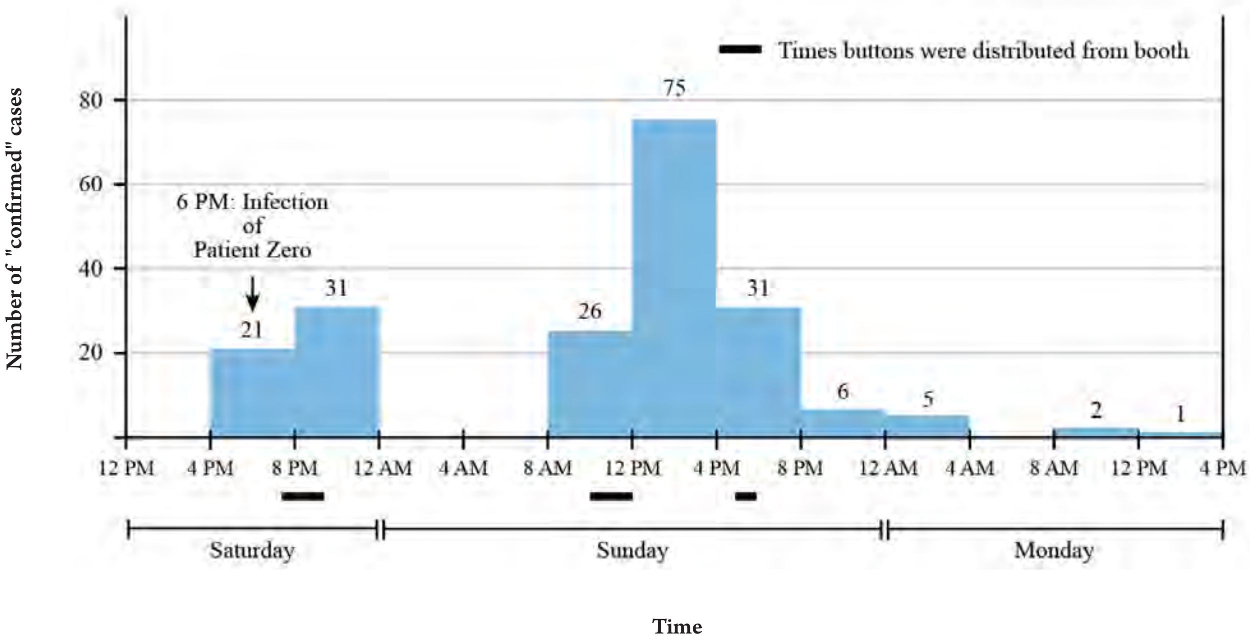

Figure 3. Epidemic curve of the mock norovirus outbreak. The number above each bar corresponds to the number of "confirmed" cases presenting at any 4-hour time interval

the presence of a pool of unconfirmed cases. However, as a teaching point, this exercise was able to highlight this phenomenon in the gray nodes on the node tree *(Fig. 4)*. Lastly, the exercise involved only person-to-person transmission and not foodborne or environmental spread of norovirus, which was both a limitation and a strength, as it allowed for direct tracking of disease spread between individuals.

Setting an upper limit of transmission at 10 buttons per person affected the maximum possible R_0 in the experiment but allowed for a larger group of participants. A single accepted R_0 value for the human norovirus does not currently exist, but values used in the literature have ranged from 1.64 to 4.92 (for children in a developed nation) to as high as 14.0 (for people of areas of poor hygiene in developing nations) *(6, 13)*. For an actual outbreak at a large gathering, the R_0 dropped from 7.26 to 1.0 over time as the outbreak was managed *(11)*. Interestingly, while somewhat on the low side at 2.48, the estimated R_0 in this experiment was within the range observed by others for natural outbreaks. Our use of a weighted average to calculate R_0 was atypical, but the numerous methods of determining R_0 that exist often involve multiplying the duration of infectiousness by the rate of new infections *(10, 15)*. In the mock outbreak, there was no true duration of infectiousness; thus with fewer variables than in real life, weighted averages were a logical approach.

Use and modification by other groups

This exercise was designed as an enjoyable way of engaging a relevant audience so as to pique their curiosity about an important public health issue. The relative simplicity of the experiment's design should make it useable by schools or by other groups wishing to educate large numbers of people on person-to-person disease transmission. Step-by-step instructions for educators are available in the Educational Materials section of the NoroCORE website. Ideally, this teaching tool would have two components when used in an educational setting: the transmission experiment itself, and the completion of statistical analyses (creation and interpretation of epidemic curves, calculation and interpretation of R_0, etc.).

CONCLUSIONS

To our knowledge, a mock disease outbreak such as this has not been conducted at a conference or large gathering, nor has one that is prospective in nature or that is directed at educating the public on infectious disease transmission. We similarly have not identified a group that has used networks to visually depict the interconnectedness of disease transmission for educational purposes. This citizen science experiment served the dual roles of fostering engagement with the conference attendees and educating them about norovirus infections and other diseases spread by person-to-person contact. A major boon of this experimental design was that the resulting outbreak was participant driven and

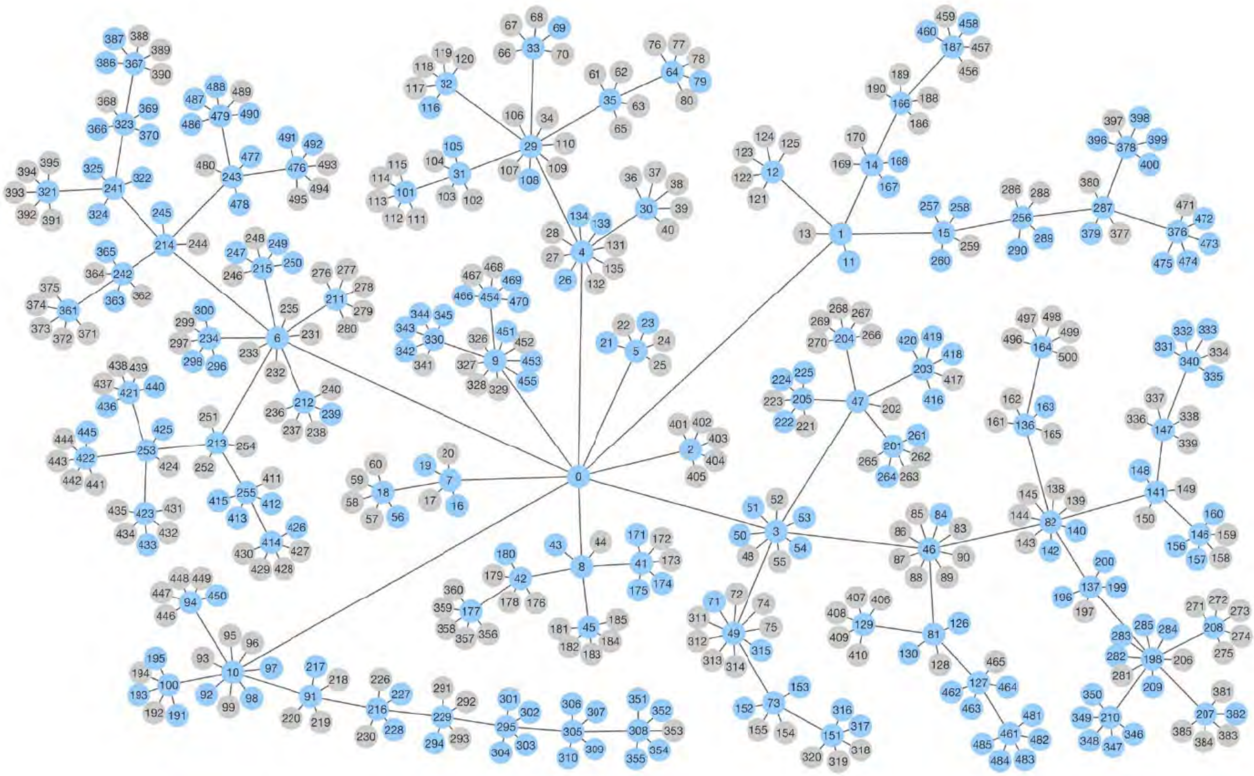

Figure 4. Node-link tree of the entire mock norovirus outbreak generated using Cytoscape 3. Blue = "confirmed" case (subject who visited the booth after "infection"), Gray = "suspected" case (subject who did not visit the booth after "infection"). Numbers in the circles correspond to the button numbers of individual players

evolved organically on the basis of actions of the infected individuals. It was also very inexpensive to implement. This exercise can be used as a simple yet effective tool to demonstrate person-to-person disease transmission and introduce classic epidemiological concepts in various educational venues.

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