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Modeling the role of public health education in Ebola virus disease outbreaks in Sudan

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A B S T R A C T

Public involvement in Ebola Virus Disease (EVD) prevention efforts is key to reducing disease outbreaks. Targeted education through practical health information to particular groups and sub-populations is crucial to controlling the disease. In this paper, we study the dynamics of Ebola virus disease in the presence of public health education with the aim of assessing the role of behavior change induced by health education to the dynamics of an outbreak. The power of behavior change is evident in two outbreaks of EVD that took place in Sudan only 3 years apart. The first occurrence was the first documented outbreak of EVD and produced a significant number of infections. The second outbreak produced far fewer cases, presumably because the population in the region learned from the first outbreak. We derive a system of ordinary differential equations to model these two contrasting behaviors. Since the population in Sudan learned from the first outbreak of EVD and changed their behavior prior to the second outbreak, we use data from these two instances of EVD to estimate parameters relevant to two contrasting behaviors. We then simulate a future outbreak of EVD in Sudan using our model that contains two susceptible populations, one being more informed about EVD. Our finding show how a more educated population results in fewer cases of EVD and highlights the importance of ongoing public health education.

1. Introduction

The Ebola Virus Disease (EVD) has posed a serious health threat to African countries since the mid 1970s. The disease was first detected in Sudan in 1976, but 21 additional outbreaks have since occurred in Central and Western Africa resulting in over 28,000 total cases (Ebola Virus Disease, 2015; Moghadam, Omidi, Bayrami, Moghadam, & SeyedAlinaghi, 2015). While past

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outbreaks each produced less than 500 cases, the recent 2013 occurrence of EVD in West Africa produced over 28,000 cases, the most cases of EVD to date (Ebola Virus Disease, 2015). The stark difference in the number of cases between various outbreaks makes predicting the severity of future outbreaks difficult. Specific transmission dynamics and resulting case counts are dependent on a number of factors including the specific strain of EVD, the population size of a given region, and specific human behavior that can either reduce, or contribute to, the spread of the disease (Dietz, Jambai, Paweska, Yoti, & Ksaizek, 2015).

The reservoir for Ebola is believed to be animals such as bats and monkeys (Olival & Hayman, 2014; World Health Organization,); outbreaks of Ebola begin after an animal from the reservoir infects a human. The disease has an incubation period of 2–21 days (World Health Organization Ebola Response, 2014; World Health Organization,). Once the virus is in the human population, individuals can contract the disease after coming in contact with the bodily fluids of an infected individual, which can include contact with someone who has died from EVD. This transmission route is exacerbated by the virus as additional bodily fluids are produced by the disease resulting in vomiting, deification, and bleeding. Since there is not yet a vaccine available, patients are treated with oral or intravenous fluids in addition to treating specific symptoms (World Health Organization,).

Cultural practices in West Africa play a large role in the transmission of Ebola (Dietz et al., 2015). When a family member becomes ill, it is common practice to forgo seeking medical treatment and instead see a traditional herbalist or be cared for at home. This is especially true in the case of Ebola as early symptoms are similar to those of influenza. Being cared for by family members often results in numerous relatives contracting the disease (Fitzpatrick et al., 2014). Another highly affected area outside the home is in health care settings. In fact, if protocols are not followed, hospital settings can produce a significant number of cases during Ebola outbreaks (Cook et al., 2015; Olu et al., 2015). It is common practice for deceased individuals to be washed, embraced, kissed, and prepared for burial by family members (Brainard, Hooper, Pond, Edmunds, & Hunter, 2015). This is problematic as deceased individuals still carry, and are capable of spreading, the virus. Even highly educated individuals who are aware of an ongoing Ebola outbreak may participate in such cultural practices. As a result, burial practices also play a major role in spreading the disease (Cook et al., 2015).

From past outbreaks it is clearly evident that taking precautions against spreading Ebola can quickly reduce or eliminate an outbreak (Brainard et al., 2015). For example, early projections during the 2014 outbreak of EVD in West Africa estimated that, without any intervention, as many as 1.4 million cases could be produced over the course of the epidemic (Meltzer et al., 2014). However, the World Health Organization declared the outbreak to be an "international health emergency" (IHR Emergency,). As a result, a significant international intervention was launched that coordinated aid from numerous entities and included massive information campaigns to educate the general public about preventing the spread of EVD. The aid included health care resources for the affected countries, and the information campaigns altered individual behavior, which quickly contained the outbreak and limited the total number of infections immensely (Chowell, Simonsen, Viboud, & Kuang, 2014). Additionally, considering the cases of Ebola that occurred in the United States and Europe during the 2014 outbreak in West Africa, careful precautions were taken by the European and American population and governments, which prevented secondary outbreaks from occurring.

The effects of public health education on the evolution of a disease have been studied in the cases of HIV (Bhunu, Mushayabasa, Kojouharov, & Tchuenche, 2010; Del Valle, Hethcote, Hyman, & Castillo-Chavez, 2005; Mukandavire & Garira, 2007; Mukandavire, Garira, & Tchuenche, 2009), drinking dynamics (Xiang, Song, & Huo, 2016), Hepatitis C virus transmission dynamics (Mushayabasa & Bhunu, 2012), and Ebola (Fast, Mekaru, Brownstein, Postlethwaite, & Markuzon, 2015; Shen, Xiao, & Rong, 2015). Mathematical models have been used to evaluate the potential role of interventions against the Ebola virus disease. Interventions aimed at reducing the burden of the 2014 Ebola virus disease epidemic were incorporated into mathematical models, see for instance (Agusto, Teboh-Ewungkem, & Gumel, 2015; Djiomba Njankou & Nyabadza, 2016; Drake et al., 2015; Kucharski et al., 2015; Pandey et al., 2014; Rachah & Torres, 2015; Tambo, Ugwu, & Ngogang, 2014; Browne et al., 2014).

Studies have shown that the prevalence of any epidemic is strongly dependent on the social behavior of individuals in a population (Del Valle et al., 2005; Xiang et al., 2016). This is evident in two early Ebola outbreaks in Sudan where the relative magnitude of each outbreak was a reflection of preparedness of health care providers and knowledge of the general public about the disease (Baron, McCormick, & Zubeir, 1983; Report of a WHO/International Study Team, 1978). Our goal was to assess how behavior change induced by education can alter the dynamics of an outbreak of EVD. We approach this question by formulating a deterministic model in which a community has two types of individuals: one that is educated about Ebola and takes precautions to avoid contracting the disease, and a second that does not take precautions against contracting or spreading the disease. Our results illustrate the importance of education as a preventative measure against contracting Ebola.

We partition the susceptible population into two groups: individuals who have not yet been influenced by public health education and those who have been educated. Unlike previous models which simply reduce various rates as a result of public health education (Fast et al., 2015; Shen et al., 2015), we estimate different parameters for each group. This approach is similar to specific preceding models in (Joshi, Lenhart, Albright, & Gipson, 2008, Joshi, Lenhart, Hota, & Agusto, 2015). We use data from the aforementioned Ebola outbreaks in Sudan to parameterize our model and also include the effect of information on increasing the rate of infected individuals seeking professional health care (Baron et al., 1983; Report of a WHO/International Study Team, 1978).

In the next section we formulate a model for the case with an educated class and an uneducated class. In section three, parameters are estimated separately for each class using a reduced version of our model. The parameters governing the uneducated class are obtained using data from the Sudan 1976 outbreak and the parameters for the educated class are estimated