Stress-related immunosuppression in disease outbreak dynamics

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Outline of presentation

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- Introduction
- The Model
- The Model Analysis
- Numerical simulations
- Results and Discussion
- Work in progress

Aim

- To explore the impact of epidemic-related stress on physiological immunocompetence expressed as the ability to withstand pathogen exposure.

Objectives

- Develop a traditional compartmental model, in which all healthy individuals within a population share equally the
  - stressful burden of caring for the sick,
  - experience the emotional sense of loss from any disease-related deaths in the population

Objectives

- Investigates mechanisms of stress experienced by healthy individuals:
  - as they try to meet the burdens of providing adequate care for the sick
  - due to death of friends and relatives.
- Develop a network based model, in which both burden and loss are the result only of the health of an individual’s direct social contacts.
- Analyse the impact of tress in the epidemic dynamics
- Determine how the change in stress level affect the shape of the epidemic

Introduction

- What is stress? - negative life events, eg
  - Death of loved ones
  - Sickness - extreme fear, worry at the outbreak of an epidemic
  - loss of a job, etc
- Emotional stress is also known to have profound negative effects on immune function.
- Stressors lead to distress

Introduction

- Association between stress and physiological immunosuppression has been well established,
- T.Herbert and S. Cohen (1993), A. O'Leary (1990), J.R.Calabrese et al (1987), B.Lerner (1996) etc:
  - stress is associated with changes in human immunity
  - substantial evidence for a relation between stress and decreases in functional immune

Introduction

- large immune changes have been found to be more in objective stressful events than in subjective self-reports of stress.
- immune response varies with length of stress
- stress may lead to decreased immune function and thus to clinical disease

Introduction

- Few studies explored the impact of stress effects on the projected dynamics of epidemics, eg B. Lerner (1996) on the TB dynamics.
- In epidemiological context - compromised immune function and their impact on disease epidemics
  - HIV/AIDS
  - opportunistic infections
- These studies have focused on direct, pathogenic immunocompromise.

Deterministic Model

- A finite population of n people classified as
  - susceptible S
  - E people exposed to the disease at a rate β, who may or may not develop active infections
  - β, - rate of contact between susceptible and infectious individuals
  - E represents the early stages of pathogen propagation during which the immune system is fighting the infection.
  - infected people I whom we assume to die from the disease at a rate δ

Impact of stress

- Individuals progress either to the infectious state with a probability a
- a : comprised of both a baseline probability of infection and an additional increase above that baseline as the individual experiences stress
- $a = (I/S + mD)c_1 + c_2$ if $S \geq 1$ and
- $a = (I + mD)c_1 + c_2$ if $S < 1.$
- c_1 is a scaling factor for stress,
- c_2 being the baseline probability of infection given exposure in the absence of stress

Impact of stress

- m is the relative impact of stress due to the death of the sick individual.
- E : considered able to successfully mount an immune response to withstand exposure and still avoid infection.
- E : return to the susceptible class with a probability b, defined to be $1 - a$.

Assumptions contd...

- a class of the dead D
- Assumed that there are no demographically parameters -
- mostly concerned with extremely rapid epidemics even though we might suspect that the effects of stress on disease dynamics may be critically important within slower outbreaks (such as HIV or TB) as well.

Model Equations

$$
\begin{aligned}
\dot{S} &= -\beta S I + b E, \\
\dot{E} &= \beta S I - (a + b) E, \\
\dot{I} &= a E - \delta I, \\
\dot{D} &= \delta I.
\end{aligned}
\tag{1}
$$

The graphical presentation

- Characterize contacts and links (from family households, neighbours, work places), that potentially lead to the disease transmission in a particular community.
- Each individual in the community is considered as a vertex, v,
- Lines connecting corresponding vertices represent contact between them.
- Transmission of disease may occur between two individuals only if there is a line connecting them.

Network model

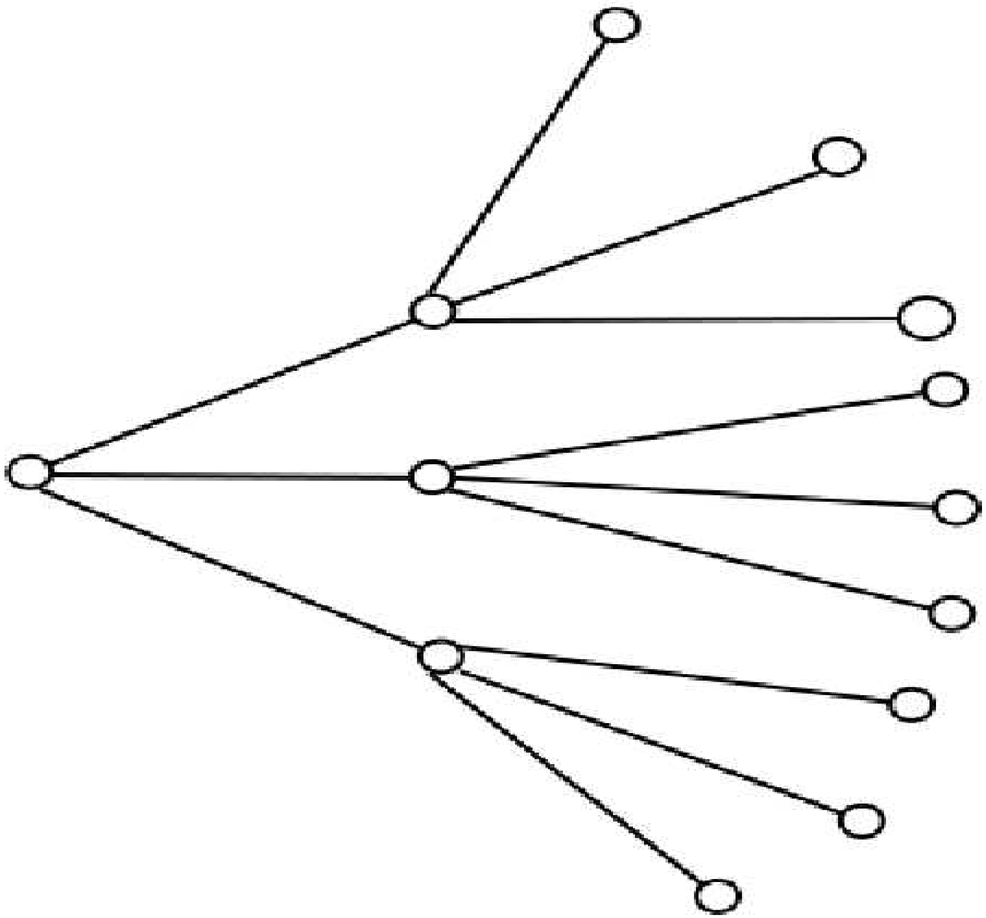


Figure 1: The graphical presentation

Impact of stress

- Variables represented by nodes are S, I and D
- E is represented by an edge between S and I since exposure happens when there is contact between the susceptible and the infectious individual
- E is only a decision variable .

Impact of stress

- A connected network $N = (v, l)$ is defined as a graph consisting of
  - a finite set of v nodes: $V(N) = \{v_1, v_2, v_3...., v_n\}$
  - a set l of lines: $E(N) = \{l_1, l_2, l_3, ..., l_L\}$,
  - If the line $l_k = (v_i, v_j) \in E(N)$ then v_i and v_j are adjacent.
- The degree, $deg(v,)$ of a node as the number of nodes adjacent to it.

Amount of stress

- $a(v)$ is the amount of stress felt by the individual v, which is then scaled by $\hat{c}_1$ and added to $\hat{c}_2$ to get the probability of infection given exposure.
  - $a(v) = \frac{deg_t^I(v)}{deg_t^S(v)} + \hat{m}\left(\frac{deg_0(v) - deg_t(v)}{deg_0(v)}\right).$
  - Assume that at time $t+1$, the probability that an individual moves from one state to the other depends on the status of the individual's contacts at time t.

Impact of stress

- Baseline probability of infection from exposure is the same (without the impact of stress) no matter how many different routes of exposure exist
- Impact of stress is greater the more of your friends are sick, but that does not change the baseline probability of transmission from exposure.

Impact of stress

- $Prob_v(S \rightarrow I | v \in S$ and $deg_t^I(v) > 0) = a(v)\hat{c}_1 + \hat{c}_2$,
- where $\hat{c}_1$ is a scaling factor for stress and
- $\hat{c}_2$ is the baseline probability of infection given exposure in the absence of stress.
- The probability of the infectious individuals dying due to the disease is $Prob_v(I \rightarrow D | v \in I) = \hat{\delta}$.
- We have denoted the network process parameters with the hat to indicate that they will represent the same concept, but will not be of the same value.

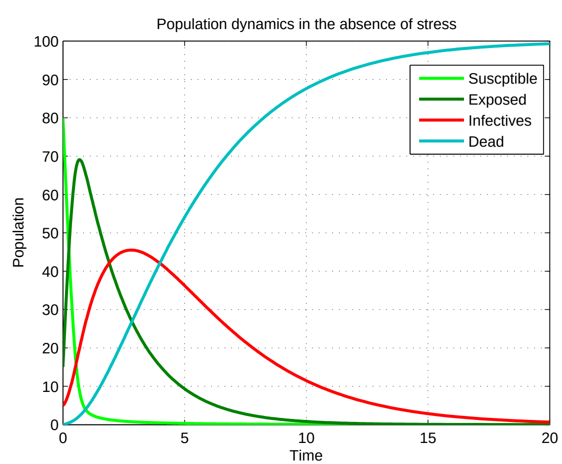
Analysis of the deterministic model

- How does stress change the dynamics of the epidemic?
- The parameter values are dependent on the size of the population, n
- The parameter m, the stress factor due to death.
- The scaling factor for stress c_1 must satisfy the following relation
  - $c_1 < \frac{1}{mn}$
  - $c_2 \leq 1 - mnc_1$.
- This ensures that $a \leq 1$.

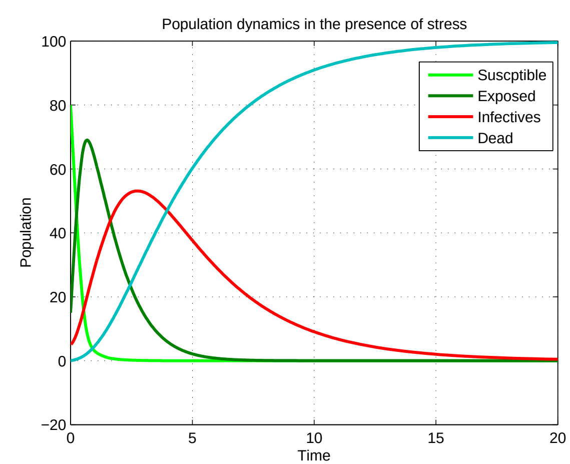
Numerical Simulations

- We consider a hypothetical population of 100 individuals and vary the death stress factor m.
- Considering the dynamics of the epidemic without stress and in the presence of stress.

(a)

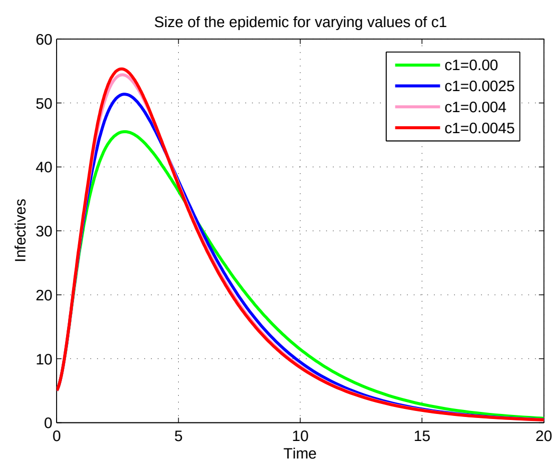


(b)



Varying c_1

- Main parameter is the rate of becoming infectious affected by the impact of stress a,
- Determined by $c_1 -$ vary the this parameter to determine the impact of stress on the dynamics of the epidemic with m constant.



Results so far

- In the absence of stress the exposed individuals take nearly twice the time taken to be infectious compared to when there is stress.
- In the presence of stress the population is wiped out in about half the time it would have survived when there is no stress.
- Few infectives compared to when there is stress
- Still to work on the numerics for the network model

TO GOD BE THE GLORY

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- THANK YOU, MERCI, SIYABONGA, TATENDA
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- QUESTIONS, COMMENTS, SUGGESTIONS?????????????
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- ARE WELCOME