Can we Learn from Animal Adaptations in HIV Prevention

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Abstract

The relationship between an individual's infection rate and the abundance of the number of susceptibles (individuals that can be potentially infected) is the functional response of an infective. We consider defensive attitudes for HIV prevention (primary prevention) and attitudes that reduce infection for those infected (secondary prevention) in this paper. We consider how animals survive predation and parallel their defense to how an uninfected individual can develop some protection from infection. Infection, in this paper is believed to follow some pattern. We propose an infection cycle that begins with a search, then an encounter, a proposal and contact. The infection cycle illustrates the various steps an infected individual goes through to successfully infect an uninfected individual. Heterogeneous transmission of HIV, requires contact for an infection to occur. The ability to avoid an encounter, detection, proposal and contact constitute defense. We present our results graphically to illustrate the benefits of various defensive attitudes.

Keywords: functional response, defense, infection cycle, protection, SSS equation.

AMS Classifications: 92B05; 92D30; 93D20;34D23.

1 Introduction

Southern Africa remains the epicentre of the global AIDS epidemic. Of the estimated 24.9 million HIV-infected people in 2003, 46% were from Southern Africa [17]. The epidemic however seems to be stabilising at high prevalence levels. Alarmingly, in Southern Africa, more than 75% of young people living with HIV are women, and the impact on women aged 15-24 years is suprisingly disproportionate, in that they are at least three times more likely to be infected than their male counterparts [17]. This has been largely due to gender inequality related to gender norms, poverty, mobility and violence against women.

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Percentage estimates of HIV prevalence among pregnant women in Southern Africa is tabulated below;

Country	% HIV prevalence	Country	% HIV prevalence
Angola	3	Namibia	20
Botswana	37	South Africa	29.5
Malawi	20	Swaziland	43
Lesotho	27	Zambia	20
Mozambique	19	Zimbabwe	21

Table 1: Source UNAIDS 2005.

Scientists have given different theories and explanations for the rapid spread of HIV/AIDS in Southern Africa, some based on, biological and social aspects[4], economic and political processes [14]. Complexities such as regional diversities in cultures, sexual behavior and migration remain unexplained by these theories [2]. One can then argue that the spread of HIV/AIDS is not only influenced by an individual's actions but also by political, social and economic standards of a society. The dynamics of HIV/AIDS is thus multidimensional and can not be focussed from a single approach.

Mathematical models have also been used to model the dynamics of HIV/AIDS. Incorporation of interventions in these models has attracted significant attention in recent years [12, 13]. The epidemiology of HIV/AIDS has moved beyond the virus and the risk factors associated with its transmission to a more detailed understanding of the mechanisms associated with the spread, distribution and impact of any intervention on the population. In HIV epidemiology, mathematical models can describe the position of individuals within networks of sexual partners via which infections spread allowing an identification of risks for acquiring and transmitting the infection. The population patterns of HIV incidence can be simulated based upon descriptions of patterns of sexual behavior and viral biology and compared with observed patterns to test our understanding. Consequently, the impact of health policies, such as poor access to care, delayed treatment or the use of screening for asymptomatic cases can be calculated [3]. The process of presenting a model to describe the spread of HIV is accompanied by underlying assumptions and the data to estimate parameter values for the qualitative and quantitative predictions that can be compared with experimental or observed patterns.

In this paper we look at recent research advances in ecology and conceptualize them in the context of HIV spread. As a form of adaptation, many animals have developed defences against their predators in a bid to outwit them. To avoid being wiped out, prey reduce predation risk by disrupting the predation cycle; search, encounter, detect, attack and feed. It has been shown that prey defensive attitudes are essential for survival and that predator offensives increase their predation changes [6]. Prey defenses can be a stabilizing factor in predator-prey interactions. Predation can be a strong agent of natural selection. Easily captured prey are eliminated, and prey with effective defenses (that are inherited or learnt) rapidly dominate the population. In the case of HIV/AIDS, the uninfected individuals must have defensive attitudes that can protect them against diseases and reduce the risk of contracting the diseases. On the other hand, those that are infected must have offensive attitudes that reduce the chances of spreading the disease. We consider HIV/AIDS as an example, and argue that we can apply the predator-prey interactions to model the spread of HIV among human individuals where prey defences can be used to avoid infections. One can argue that predators look for prey for survival and infected individual can survive without sexual encounters. It is apparent that when infected individuals are on a revenge mission, the predator instincts will be controlling them. Lack of counselling services, declining health standards and loss of hope in the event of HIV contraction has led to individuals having discovered that they are HIV positive, opting for revenge and the 'the I will never die alone' attitude. We can consider those with the virus to be predating on the susceptible population. In many mathematical models, the infected have been subdivided into classes of those that are under treatment and those with full blown AIDS, but with one thing in common, i.e they are still infectious [13]. Prey defensive attitudes diminish the population that predates on the prey and this will result in the control of HIV. It is therefore important to emphasize more on the defensive attitudes for HIV prevention (primary prevention) while at the same time dealing with the offensive attitudes of those infected (secondary prevention).

We consider work by Jeschke J. M., [6, 7, 8, 9, 10]. In our study, sexual encounters are responsible for the loss of susceptibles (the prey, individuals without the HIV). Just as the predator per capita feeding rate on the prey, i.e its functional response, provides the foundation for predator prey interaction, the sexual encounter rate of an infected individual plays a vital role in the spreading of HIV. While the predator's feeding rate represents the transfer of biomass between trophic levels [16], the rate of sexual encounters by an infected individuals represents the transfer of the virus, resulting in the loss of susceptibles. My objective is to use the SSS (steady state satiation) equation derived in [8], as a functional response model to model how the defences of the susceptibles qualitatively affect functional response in the case of an HIV infected individual preying on the uninfected susceptibles.

2 Model

The avengive characteristics of an HIV infected individual are divided into five stages, corresponding to the predation cycle: search, encounter, detection, proposal and sexual encounter. We assume here that all these stages are gender independent. The determination to infect a large number of individuals is equivalent to the hunger level of predators in an ecological setting. The predation rate when there is a high density of susceptibles is limited by the handling time or satiation. A single predator and a single prey type is assumed. We also assume that the predation cycle stages are mutually exclusive.

As given in [6, 8], searching stage, is the entry stage for an infected individual, with the probability that he/she will search being $\alpha(N)$, where N is the density of infectives. As in [8], $\alpha(N) = 1$ if an infected is not involved in an affair and

$$\alpha(N) = 1 - cy(N).$$

$\alpha(N)$ is directly proportional to the level of revenge. The level of revenge depends on whether the infected is satisfied that the intended objectives have been reached. It is reasonable to assume that the level of revenge will reach a steady state at some time, hence we can use the SSS equation. For the derivation of the SSS equation, the readers are referred to [8].

The SSS equation is given by

$$y(N) = \begin{cases} \frac{1-a(b+c)N-\sqrt{1+a(2(b+c)+a(b-c)^2N)N}}{2abcN}, & \text{if } a,b,c,N > 0, \\ \frac{aN}{1+abN}, & \text{if } b > 0, c = 0, \\ \frac{aN}{1+acN}, & \text{if } b = 0, c > 0, \\ aN, & \text{if } b = c = 0, \\ 0, & \text{if } a = 0 \text{ or } N = 0. \end{cases}$$

where $y(N)$ is the predation rate (the number of susceptibles infected per given time), a is the success rate, b, the handling time (the time between two consecutive sexual partners) and c is the processing time (depends on the level of satisfaction of goal achievements and the time it takes to do so). The success rate

$$a = \beta\gamma\delta\epsilon$$

is a product of β, the encounter rate between an uninfected individual and an infected individual, γ, the probability that an infected individual detects an uninfected individual, δ, the probability that detection results in a proposal and ϵ the disease transmission efficiency. The disease transmission efficiency can be taken to be the probability that a successful proposal results in a sexual encounter that results in an infection. Proposals are usually based on the derived benefits of the action. For example, for an infected woman who needs support, δ would be the probability that the woman in question detects the availability of the support. Handling time depends on the time spent proposing per an uninfected individual, t_p, the time spent in sexual encounters per an uninfected individual, t_e, and the disease transmission efficiency, ϵ;

$$b = \frac{t_p}{\epsilon} + t_e.$$

Short handling times are likely to increase the spread of the disease. Delayed sexual encounters by the youth can be interpreted as increasing the handling time. The handling time, depends on the capacity of an infected individual to handle a given number of relationship. A rich infected individual is more likely to handle many relationships due to the means to do so. The processing time determines how soon the next search will come. For $c = 0$, there will be no satiation

3 Survival of susceptibles

Susceptibles can survive the HIV/AIDS scourge if their defensive attitudes decrease the success rate of the infectives. Educational campaigns in the fight against HIV are aimed at preventing new searches, increase the handling time and preventing new infections on proposals that have been successful. The ability of the susceptibles to handle life issues (e.g women empowerment, education, sexual risk-reduction skills, strong marriages etc.) increase the handling time. It also increases the processing time $\mathcal{C}$, thus reducing the infected individual's desire to go for the next search. Predator avoidance strategies are important for survival because they prevent encounters and detection that lead to proposals.

Protection of children in their most vulnerable state is of primary importance to prevent and minimize encounters with the infected. This protection may be in the form of sex education. Uninfected individuals should by all means avoid areas where the high risk group frequently visit in a bid to minimize encounters with the infected. While it is difficult to prevent detection and encounters, it is not difficult to prevent the success of a proposal or a contact. In the event that a successful proposal results in sexual encounters, protective behavior will prevent infection i.e the use of condoms. Naturally, some prey can survive by responding to intimidation [18]. One can also argue that increasing the number of activities, in the form of exercises and social grouping can reduce the time spent in sexual activities. The underlying principle is that, one can not be infected unless their is contact, in the case of heterosexual transmission. Survival of sucsceptibles largely depends on the reduction of the infection rate.

A comparison of the disc and SSS equation are given in Fig. 1. The disk equation assumes that every proposal is successful and the infective does not become satiated. This has been deemed unrealistic as species behave adaptively and their density is important[1, 8].

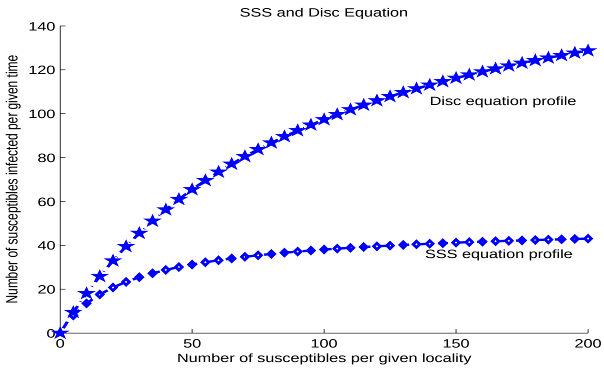

Figure 1: The infection rate as depicted by the disc and SSS equations for the following parameter values:$c = 0.02,\ \beta = 20,\ \gamma = 0.1,\ \delta = 0.95,\ q = 5,\ p = 0.3,\ \phi = 0.3,\ b = 0.01$

Condom use has been advocated for in recent years as a means to reduce new infections. We observe in the graph below that increased condom preventability is accompanied by a decline in the number infectives. This is so because increasing p reduces the disease transmission efficiency ϵ. For example, if $p = 0.9,\ \epsilon = 0.15$ and if $p = 0.7,\ \epsilon = 0.45$. A contrasting result is obtained when the transmission probability is increased. Increasing ϕ leads to an increase in the disease transmission efficiency ϵ.

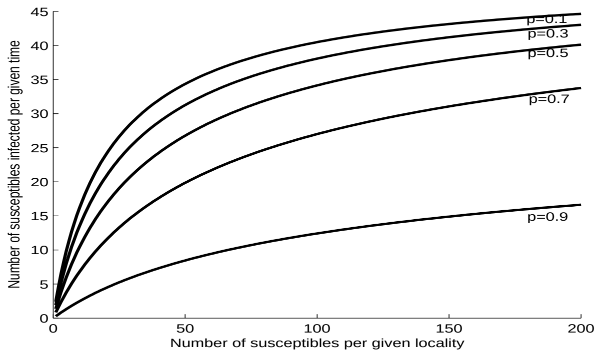

Figure 2: The graph shows how the infection rate varies as the value of p changes, for the following parameters: $c = 0.02,\ \beta = 20,\ \gamma = 0.1,\ \delta = 0.95,\ q = 5,\ \phi = 0.3,\ b = 0.01.$

The level of awareness about a disease is critical if desired levels success in disease prevention are to be realized. We vary the level of awareness in the SSS equation and the results are graphically presented below.

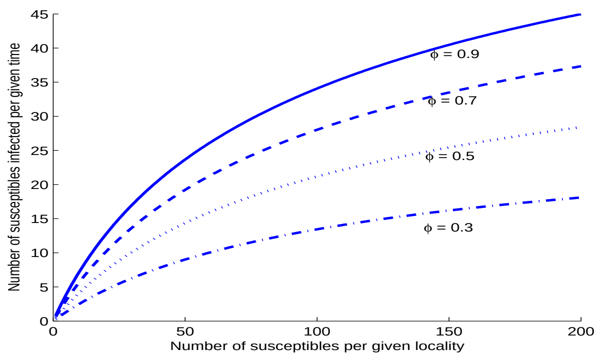

Figure 3: The infection rate as depicted by the SSS equations for the following parameter values:$p = 0.9,\ \beta = 20,\ \gamma = 0.1,\ \delta = 0.95,\ q = 5,\ b = 0.01$ with ϕ being varied.

4 Discussion and conclusion

Prey defensive attitudes diminish the population that predates on the prey. HIV/AIDS is a disease that is preventable through behavioral change. To develop appropriate HIV prevention interventions strategies, a lot of factors have to be considered. These include risk-related cognitive and attitude factors (incorrect beliefs about the disease, weak intentions to change behavior, negative attitudes towards condoms, poorly perceived self efficacy), poor risk reduction skills (correct condom use, limited power to negotiate safe sex) and poor social support structures [11]. The spread of HIV/AIDS, especially in Southern Africa has been attributed to the complex social networks, diverse cultures and cultural practices, poverty, substance abuse, migration etc. The main focus in the fight against the disease has been on prevention through behavioral change with the aim of preventing new infections. One way in which those that are not infected can avoid infection, is to develop defense mechanisms that ensure survival. Studies have shown that predators prefer to hunt small-brained animals [15]. One can argue the need to have a strong resolve, will and mind in order to survive the HIV/AIDS pandemic, especially in an environment where one in every three are infected (the case of Botswana, Swaziland and Lesotho in Southern Africa) [17]. To have significant success in HIV prevention, individuals must avoid and defend themselves from infection. By defence, we mean any characteristic that reduces the likelihood of one getting infected.

The HIV virus has been characterized by rapid evolution and high rates of genetic mutation. It is known that virus evolve rapidly in response to survival threats such as the anti-retroviral drugs (ARVs) and as such the fight against HIV using pharmaceutical products will always remain elusive. This has made scientific progress in the fight against the virus very slow. At the mean time, the possibility of achieving mutual coexistence

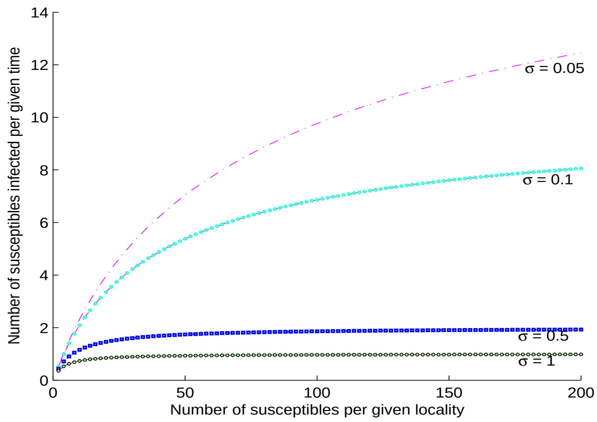

Figure 4: The infection rate as depicted by the SSS equations for the following parameter values:$p = 0.9,\ \beta = 20,\ \gamma = 0.1,\ \delta = 0.95,\ q = 5,\ \phi = 0.3,\ b = 0.01$ with σ being varied.

between HIV and humans should be supported. The advent of ARVs means humans must adapt to the presence of HIV in the population, while making sure to avoid infection by sound defensive mechanisms.

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