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Modeling the impact of supra-structural network nodes: The case of anonymous syringe sharing and HIV among people who inject drugs

Lindsey Richardson *, Thomas Grund [1]

Nuffield College, University of Oxford, New Road, Oxford OX1 1NF, UK

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ABSTRACT

Networks are well understood as crucial to the diffusion of HIV among injection drug users (IDUs), but quasi-anonymous risk nodes – such as shooting galleries – resist measurement and incorporation into empirical analyses of disease diffusion. Drawing on network data from 767 IDUs in Bushwick, Brooklyn, we illustrate the use of calibrated agent-based models (CABMs) to account for network structure, injection practices, and quasi-anonymous transmission in shooting galleries. Results confirm the importance of network structure and actor heterogeneity to the magnitude and speed of HIV transmission. Models further demonstrate that quasi-anonymous injections in shooting galleries increase the speed of HIV diffusion across the whole network and have the greatest impact on HIV seroconversion levels for IDUs at the network periphery. Shooting galleries are shown to be transmission hubs that operate independently of traceable structural ties, linking otherwise unconnected network components. CABMs potentially increase understandings of HIV diffusion dynamics by infusing computer simulations with empirical data.

1. Introduction

The injection of illicit drugs is associated with various harms, including the spread of blood-borne disease such as HIV (Aceijas et al., 2004). While HIV infection among injection drug users (IDUs) has decreased in some settings, such as the US (Hall et al., 2008), in other contexts, including Eastern Europe and Central Asia, rates of transmission among IDUs remain alarmingly high (UNAIDS, 2010). Networks are crucial to understanding the diffusion of HIV infection among IDUs. The mixing patterns of individuals, when combined with the non-random distribution of HIV-risk behaviors within social networks, have demonstrated that the structure of social networks has implications for HIV transmission over and above the effects of individual characteristics and behaviors (Klovdahl, 1985; Friedman, 1995; Potterat et al., 1999).

Despite the importance of network structures to disease diffusion, less is known about the role and impact of quasi-anonymous disease transmission hubs such as shooting galleries, where individuals know little or nothing about their injection partners (Friedman et al., 2007). Shooting galleries are often omitted from models depicting the spread of HIV disease. They transcend the traceable structures of the network and form supra-structural nodes, having potentially significant impacts on patterns of disease diffusion. Existing studies that consider these dedicated mixing sites generally use compartmental or differential equation (DE) models (see, for example, Volz et al., 2011). We propose the use of another promising methodological strategy – calibrated agent based modeling – to isolate the potential effect of shooting galleries on HIV diffusion in risk networks of IDUs. The purpose of the current study is therefore to apply calibrated agent based models

* Corresponding author.
E-mail addresses: lindsey.richardson@sociology.ox.ac.uk (L. Richardson), thomas.u.grund@gmail.com (T. Grund).
[1] Present address: ETH Zurich, Chair of Sociology, Modeling and Simulation, Clausiusstrasse 52, 8092 Zurich, Switzerland.

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(CABMs), a network-based analytical strategy, to explore how supra-structural network nodes impact the transmission of HIV in a network of IDUs.

Previous research has established the role of social relationships in the diffusion of HIV among IDUs, demonstrating that they matter for both individual risk behaviors (Tyler, 2008) and HIV infection (Goodreau, 2006). Social influence has been suggested as a crucial mechanism by which network structure and levels of social integration predict individual health outcomes (Berkman et al., 2000). This influence may operate, for example, through processes related to the diffusion of individual behavior or norms (Rogers, 2003; Latkin et al., 2010) or personal network exposure, which describes the extent to which a network member is exposed to a particular practice (Valente, 2005; Gyarmathy and Neiagus, 2006). Empirically, drug using practices of "alters" (i.e. an individual with whom a person shares a tie, here an injecting partner), consistently predict the drug using practices of network "egos" (i.e. the individual in question) in terms of syringe sharing, shooting gallery attendance, renting syringes and sharing other equipment, such as drug cookers (Neaigus et al., 1994; Latkin et al., 1995).

Other research illustrates how the structure of drug user networks is important for disease diffusion. Existing studies suggest that the spread of HIV infection is contingent upon network structure, behavior associated with increased HIV risk, and the location of HIV infiltration and concentration within the network (Curtis et al., 1995; Price et al., 1995; Rothenberg et al., 1995, 2001). For example, in Colorado Springs, HIV positive members of the IDU network are peripherally and weakly connected to larger network chains, suggesting a network structure that does not facilitates active propagation (Rothenberg et al., 1995). In St. Louis, HIV is concentrated among injectors whose close social connections are exclusively with other drug injectors. In this case, isolated, closed networks may reduce viral spread (Price et al., 1995). IDUs in Atlanta connect heterosexual and men who have sex with men (MSM) populations, thereby indirectly driving extensive HIV transmission (Volz et al., 2010). In New York research identifies large, densely connected network components that include a network core whose members have proportionately higher HIV prevalence rates than other network members (Curtis et al., 1995), thereby facilitating greater and more rapid spread of HIV throughout the network. Spread may also depend on the location and connectivity of individuals with relatively more infectious acute HIV infections (Friedman et al., 2000).

Despite the identification of highly consequential network characteristics, network-focussed studies of HIV diffusion among IDUs face considerable obstacles, including difficulties obtaining reliable and complete network data for IDUs. Linkages between network members may be short term and between people who either do not have reliable data about one another or who are reticent to name their associates. IDUs may avoid identification by researchers or other officials because of the illegal nature of some of their activities. Subjects may also have difficulty recalling with whom they have interacted and of what their interactions were comprised (Friedman, 1995). Further, variability in the duration and content of linkages between network members makes it difficult and highly resource intensive to account for network dynamics over time. The dynamic, concealed and potentially chaotic nature of IDU networks makes them difficult to reliably quantify.

Particularly relevant to the current study are injection environments that present particular challenges for the mapping and modeling of network processes, such as shooting galleries. Shooting galleries are clandestine locations where the rental and multi-person use of injection equipment commonly occurs. Shooting galleries form and dissolve rapidly and unpredictably, and may involve IDUs that are unknown to each other and otherwise unconnected in the broader risk network. Shooting galleries have been identified as HIV 'risk environments' (Rhodes et al., 2005) and have been associated with non-recreational, high intensity drug injection, higher exposure to HIV disease and substantially elevated risk for HIV infection (Chitwood et al., 1990; Des Jarlais and Friedman, 1990; Klein and Levy, 2003). HIV transmission in shooting galleries may occur through the sharing of injection equipment between shooting gallery attendees who may or may not otherwise know each other or through the use or rental of previously used injection equipment. Previous research acknowledges the relevance of such "quasi-anonymous risk nodes" (Friedman et al., 2007, p. 645), which include group sex events, bathhouses and shooting galleries. Similarly, other studies have identified supra-individual network components that are important to disease diffusion, notably Klovdahl et al.'s (2001) seminal study of tuberculosis transmission in public places. In these contexts, conventional probes to name network members fail to identify entire sections of an individual's risk network (Friedman, 1995). Quasi-anonymous risk nodes therefore resist measurement and incorporation into empirical network analyses of disease diffusion.

These challenges often prompt researchers to use simulation models of HIV transmission among IDUs (Allard, 1990; Peterson et al., 1990; Iannelli et al., 1997). Many of these studies take contact and/or network structure into account. Kretzschmar and Wiessing (1998) demonstrate how random versus non-random mixing greatly elevates HIV prevalence. Zaric (2002) also compares the impact of random vs. non-random mixing, noting that the assumption of random mixing may lead to higher incidence and prevalence but is generally not an appropriate modeling assumption. Kiss et al. (2008) compare assortative vs. disassortative mixing patterns on epidemic dynamics, demonstrating that with assortative mixing, outbreaks occur at lower infection rates with faster epidemic growth and shorter epidemic duration. Other simulations take shooting galleries or dedicated mixing sites into account. For example, Kaplan (1989) models a homogeneously mixing population in which all needles are shared in randomly selected shooting galleries. Greenhalgh and Hay (1997) incorporate the effect of behavior change on transmission, showing a reduction in HIV transmission when injection equipment is cleaned after use. Atkinson (1996) simulates HIV spread in a single high-volume shooting gallery with varying numbers of partners and injection frequencies. These studies generally use compartmental or differential equation (DE) models that aggregate individuals into compartments within which they are considered to be homogeneous and well mixed (Zaric, 2002; Rahmandad and Sterman, 2008). However, a systematic comparison of agent based and DE models in the context of diffusion suggests that ABMs are better able to examine heterogeneity in individual attributes and network structures (Rahmandad