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ORIGINAL ARTICLE

A Social Ecological Model of Syndemic Risk affecting Women with and At-Risk for HIV in Impoverished Urban Communities

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Abstract Syndemic risk is an ecological construct, defined by co-occurring interdependent socio-environmental, interpersonal and intrapersonal determinants. We posited syndemic risk to be a function of violence, substance use, perceived financial hardship, emotional distress and self-worth among women with and at-risk for HIV in an impoverished urban community. In order to better understand these interrelationships, we developed and validated a system dynamics (SD) model based upon peer-reviewed literature; secondary data analyses of a cohort dataset including women living with and at-risk of HIV in Bronx, NY (N = 620); and input from a Bronx-based community advisory board. Simulated model output revealed divergent levels and patterns of syndemic risk over time across different sample profiles. Outputs generated new insights about how to effectively explore multi-component multi-level programs in order to strategically develop more effective services for this population. Specifically, the model indicated that effective multi-level interventions might bolster women's resilience by increasing self-worth, which may result in decreased perceived financial hardship and risk of violence. Overall, our stakeholder-informed model depicts how self-worth may be a major driver of vulnerability and a meaningful addition to syndemic theory affecting this population.

Keywords HIV/AIDS · Women · Substance abuse · Violence · Distress · System dynamics

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Introduction

A syndemic is a set of mutually reinforcing health and psychosocial problems that generate increased health risk and burden on vulnerable populations (Singer 1996). Although many studies have documented the presence of comorbidities, those applying a syndemics framework seek to assess the added risk or burden attributable to interactions among selected comorbid conditions, which often include medical, behavioral, and social factors (Mendenhall 2015). Syndemic theory has been applied to assess the co-occurrence of psychosocial forces affecting HIV-related high-risk behavior and HIV-status in men who have sex with men (e.g., Stall et al. 2003; Mustanki et al. 2007) and impoverished women (Meyer et al. 2011; Pitpitan et al. 2013). Current understanding of syndemic risk is mainly based on statistical modeling that demonstrates bivariate and additive associations with HIV infection, substance use and violence. How these forces interact over time and shape individual risk levels, however, has not been assessed and is challenging to present, due to the inherent dynamic complexities of human attitudes, emotions and behaviors.

Syndemic theory closely aligns with a social ecological framework (e.g., Singer 1996; Gonzalez-Guarda et al. 2011). This framework supports conceptualization of syndemic risk as: (1) rarely a function of a single cause; (2)

likely to be effected by combinations of factors at multiple levels of influence; (3) subject to dramatic, non-linear variations due to even small changes in one or more factors, over time; and (4) derived from both socio-environmental and individual-level processes (Lounsbury and Mitchell 2009). Moreover, per Ecological Systems Theory (Bronfenbrenner 1979), we see individuals as active agents who constantly shape, and are shaped by, their environments. Both syndemic theory and a social ecological framework are consistent with the conceptualization of syndemic risk being complex and dynamic.

The HIV-epidemic affecting women in the US involves complex and dynamic relationships between socio-environmental, interpersonal and intrapersonal factors. Women's acquisition of HIV has been associated with interrelated socio-environmental factors such as poverty and interpersonal factors such as history of violence and abuse, particularly intimate partner violence (Brier and Runts 1993; CDC 2013; Cook et al. 2007; Zierler and Krieger 1997; Simoni and Ng 2000, 2002; Somalai et al. 2000). In turn, these conditions have been linked to intrapersonal psychological and behavioral variables, including emotional distress, substance use and high-risk behaviors (e.g., transactional sex) as well as challenges engaging in condom use negotiation and obtaining information about a partner's HIV-status (Arriola et al. 2005; Crosby et al. 2013; El-Bassel et al. 2000, 2011; Lane et al. 2004; Schiff et al. 2002; Ward 1993).

Sexual self-care continues to be important in addressing the HIV epidemic among women, as the vast majority of the close to 300 thousand estimated women living with HIV/AIDS in the United States (CDC 2013) are thought to have acquired the virus from heterosexual contact (84 % of new cases; CDC 2013). However, sexual acquisition of HIV among women is dynamically related to socio-environmental problems such as poverty, interpersonal problems such as violence and individual level variables including substance use.

Consistent with syndemic theory and an ecological framework, a disproportionate number of the estimated 32,500 women living with HIV in New York City are in the Bronx, one of the poorest urban counties in the country (US Census Bureau 2010). In New York City, intimate partner violence-related hospitalizations and emergency room visit rates are both associated with living below the poverty line and neighborhood median household income (NYC DOHMH 2013). The Bronx has the highest rate of intimate partner violence-related hospitalizations and emergency room visits as well as the highest percentage of uninsured and individuals on Medicaid in New York City (NYC DOHMH 2013). To effectively understand and intervene on this complex ecological problem among women with and at-risk for HIV, we must take a closer look at syndemic theory by exploring the dynamically related socio-ecological, interpersonal and intrapersonal problems.

System dynamics (SD) modeling methodology is finding a place in the growing number of comparative effectiveness methodologies with utility in health intervention development and implementation science (Homer and Hirsch 2006; Mabry et al. 2008; Milstein 2008; Lounsbury et al. 2015; Palma et al. in press; Trochim et al. 2006). SD models are mathematical simulation tools that have great potential for fostering deeper understanding of complex public health problems (Hirsch et al. 2007). The hallmark of the SD approach is the study of feedback structures, or causal loops (Forrester 1971; Richardson 1991; Wolstenholme 1983). We applied SD modeling to visualize and assess the interdependent relationships among selected constructs that contribute to, and explain the effects of 'syndemic risk.'

We first present our conceptualization of syndemic risk, expressed in terms of multiple causal loops of selected contributing constructs, as informed by three sources of evidence (described below). Causal loop diagramming is a useful technique for illustrating how specified constructs are linked together and how they change over time. Every causal link has a polarity, either positive (+) or negative (−). A positive (+) link indicates that an incremental increase in the input (antecedent) variable causes the output (dependent) variable to also increase by a specified amount over each time increment. Similarly, an incremental decrease in the input variable would cause the output variable to decrease by a specified amount over each time increment. A negative (−) link indicates the opposite relationship between two variables, such that an incremental increase in the input variable causes the output variable to decrease by a specified amount over each time increment and vice versa. The sign given to each bivariate relationship in our model is assigned based upon a variety of sources of evidence, including pertinent findings in the peer-reviewed scientific literature and primary data and/or secondary data. Note that linking arrows between variables infer causality, not correlation.

Each feedback loop has a polarity, labeled to be either reinforcing (+) or balancing (−). The number of negative links in the loop determines the polarity of the feedback loop. An even number of negative links makes the loop reinforcing. An odd number of negative links makes the loop balancing. Reinforcing loops promote or accelerate the growth, often generating instability in the system. In contrast, balancing loops are stabilizing, or goal seeking, creating a homeostatic (steady-state) condition. The interactive effects of the loops over time produce the overall dynamics of the problem of interest. When reinforcing (positive) and balancing (negative) loops are combined, a variety of simulated patterns of change are possible. For example, two reinforcing loops may interact to bring a

particular construct into a steady state, or, alternatively, may generate an oscillating pattern over time, with one loop dominating the other in an alternating manner.

SD transforms the problem of interest into interacting structures that are specified mathematically as a set of linear or non-linear differential and algebraic equations. SD uses calculus to integrate feedback structures at simulated frequencies, thus enabling the simulation of the derivation and integration of equations over the simulated time horizon, thus simulating both the structure and dynamics of the system. The epistemology of SD enables the development of equations based on quantitative and qualitative sources of evidence, including stakeholder insight and feedback. These unique capacities of SD enable the exploration of syndemic theory as well as intended and unintended consequences of changes in syndemic problems over time. While human behaviors are complex and cannot be predicted with certainty, tools such as SD can elucidate tendencies and patterns of expected behavior, based on evidence. SD modeling has been used to explore interrelated health and behavioral problems in the past (e.g., Miller et al. 2011; Lounsbury et al. 2014). However, we are not aware of another SD modeling project used to display syndemic risk, as we have defined it, prior to this project. A detailed technical account of the methods used in this modeling project is described in Batchelder and Lounsbury (in press).

We aimed to apply SD modeling to define and understand the structure and behavior of syndemic risk affecting women with and at-risk for HIV in impoverished urban communities to increase our theoretical understanding of the social ecological drivers and inform intervention strategies. We used the model to produce scenarios to identify dynamic patterns related to syndemic risk among urban women with and at-risk for HIV to reach these goals.

Methods

SD model building is an iterative process involving three major steps: (1) system conceptualization, (2) model formulation, and (3) model simulation, inclusive of model evaluation and calibration (Richardson and Pugh 1981; Oliva 2003). System conceptualization is largely qualitative, whereby the model-building team names constructs of interest and drafts hypothesized causal influences and interrelationships. This step is typically presented as a causal loop diagram (CLD; Fig. 1), which exhibits closed feedback pathways among a set of purposefully selected, interrelated constructs. Formulation involves translating the system conceptualization into a set of equations using SD modeling software followed by structural validity checks of these equations. Model simulation involves running the SD model and examining its simulated output to achieve plausible and/or expected behavior in a process of trial-and-error. Model simulation also includes sensitivity analyses to evaluate behavioral performance in which a range of variable values is simulated to generate effects on selected outcomes. Finally, model simulation includes comparing simulated outputs to identify and assess the utility or effectiveness of various possible simulated policies or interventions. Following procedures described by Richardson (1998), we used Vensim® modeling software to create the CLD (Fig. 1) and the final SD model. (Methods for developing our model of syndemic risk are described in greater technical detail in Batchelder and Lounsbury in press).

Sources of Evidence

We used three sources of evidence to inform the development and validation of our model: (1) review of the published literature related to the identified syndemic socio-environmental, interpersonal and intrapersonal variables and women's health; (2) secondary analysis of cohort data among women with and at-risk for HIV in the Bronx and (3) qualitative feedback from the Bronx Community Research Review Board (BxCRRB).

Literature

Prior to embarking on the model-building process, a systematic literature review was conducted exploring psychosocial syndemics among women with and at-risk for HIV. Subsequently, we turned to the literature multiple times to develop and refine our system conceptualization and build equations (Richardson and Pugh 1981). We first conducted a systematic literature review, prioritizing meta-analyses and systematic reviews when available, to identify initial "syndemic" constructs of interest including emotional distress, substance abuse, perceived financial hardship, violent encounters, and HIV status (e.g., Arriola et al. 2005; Cook et al. 2007; El-Bassel et al. 2000; Logan et al. 2002; Meyer et al. 2011). Literature searches were then conducted for each bivariate relationship between constructs included in the theoretical model. We conducted an additional literature review to finalize the causal pathways depicted in the CLD, focusing on longitudinal relationships between the proposed syndemic variables and rates of change, when available. After the final CLD was completed, we revisited the literature again to confirm equations representing the bivariate relationships between constructs and to investigate relationships identified by the other sources of evidence. See Table 1 for literature review of bivariate relationships.

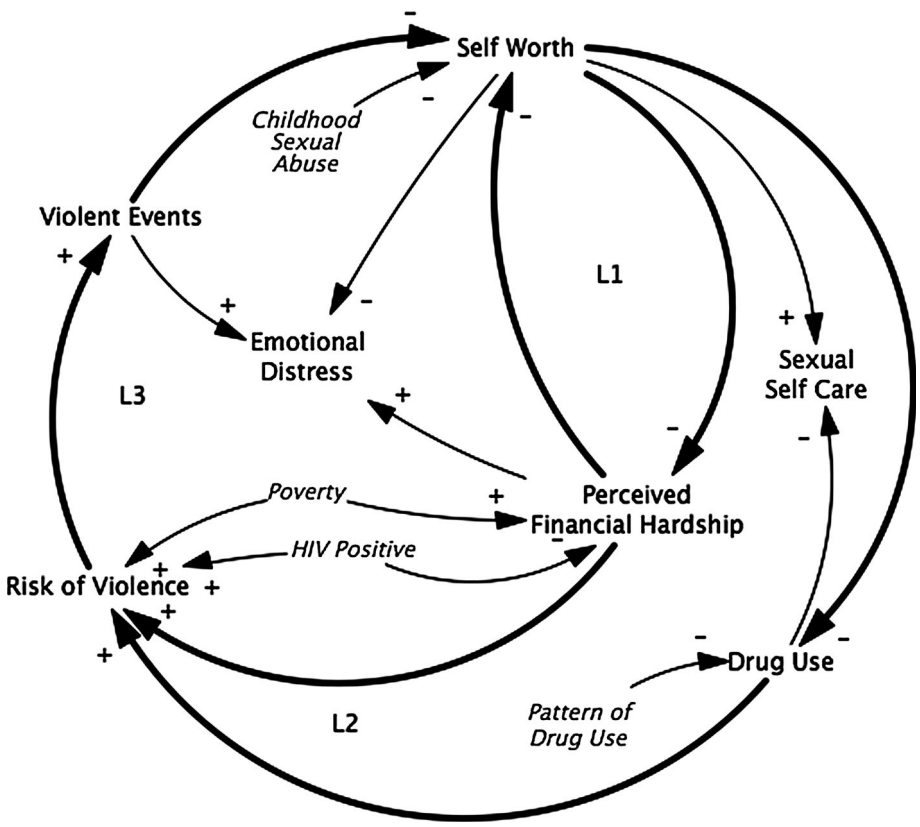

Fig. 1 Causal loop diagram of syndemic affecting women with and at-risk for HIV in the Bronx. The *arrows* show the hypothesized causal pathways between variables

Cohort Study

We conducted secondary analyses of a 4-year cohort study that recruited women living with and at-risk for HIV/AIDS in the Bronx (described in Howard et al. 2005; PI Schoenbaum; n = 620). Women in the cohort had a median age of 45 years (range 35–71); 50 % were Black and 39 % were Hispanic; 54 % were confirmed HIV + at baseline; and all endorsed past HIV-related high-risk behaviors (i.e., injection drug use, sex with known or suspected HIV infected male, >4 partners in the last 5 years, and transactional sex for money or drugs). Self-reported emotional distress, illicit substance use, violent encounters, perceived financial hardship, history of childhood sexual abuse, and HIV-status were all collected in interviews at baseline and then 6 month intervals. Substance use, violent events, history of childhood sexual abuse and perceived financial hardship were asked as single questions. Emotional distress was measured using the Center for Epidemiologic Studies Emotional distress Scale (CES-D; Radloff 1977; Coyne 1994). Sexual self-care was operationalized using a composite score including: sex with ≥1 partner in past 6 months, transactional sex, vaginal sex without a condom and anal sex without a condom. HIV-status was based on self-report and confirmed with viral load or CD4 testing. Data from all nine time-points were used to compute indicators, annualized and semi-annualized average frequency counts and to evaluate bivariate relationships between constructs over time. The cohort data were also used to inform the calibration of produced scenarios of syndemic risk dynamics.

The Bronx Community Research Review Board (BxCRRB)

The BxCRRB is a community-academic partnership made up of approximately 10 Bronx community members who work to increase the benefits of research to their community. Members were demographically similar to the population of interest. We met with the BxCRRB three times and obtained qualitative feedback about our problem conceptualization and the dynamics of syndemic risk, by presenting our initial CLD and later simulated scenarios. During our first meeting, we presented our list of initial syndemic constructs (history of childhood sexual abuse, distress, substance abuse, violence, and financial hardship as identified in our systematic literature review) without conveying our hypothesized relationships. Members were asked if the identified constructs were meaningfully related to sexual self-care and how they felt the constructs were related to one another. The members affirmed that the identified constructs were related to sexual self-care and confirmed our hypothesized interrelationships. By consensus, the members suggested we add "self-worth" to our

Table 1 Support from published literature for bivariate relationships represented in the system dynamics model[a]

Bivariate relationship	Listing of supportive peer-reviewed published literature
Endogenous constructs	
Self-worth and perceived financial hardship (*Loops 1 and 3*)	Dietz (1996), Leary and Baumeister (2000), Lundberg and Kristenson (2008), Orth et al. (2012), Selenko and Batinic (2011)
Self-worth and drug use (*Loop 2*)	Dietz (1996), Golder and Logan (2011), Gutierres and Puymbroeck (2006) (review), Orth et al. (2012)
Violence and self-worth (*Loops 2 and 3*)	Dietz (1996), Golder and Logan (2011), Gutierres and Puymbroeck (2006) (review), Orth et al. (2012)
Drug use and risk of violence (*Loop 2*)	Campbell et al. (2009), El-Bassel et al. (2005), Testa et al. (2003)
Risk of violence and violent events (*Loops 2 and 3*)	Catalano et al. (2009), Sonis and Langer (2008)
Perceived financial hardship and risk of violence (*Loop 3*)	Jewkes (2002), El-Bassel et al. (2005), NYC DOHMH (2009), Sonis and Langer (2008)
Exogenous inputs	
Poverty and risk of violence	Jewkes (2002), NYC DOHMH (2013), Sonis and Langer (2008)
Poverty and perceived financial hardship	Adler et al. (2000), Lundberg and Kristenson (2008)
HIV-status and risk of violence	Gielen et al. (2007)
Childhood sexual abuse and self-worth	Bagley and Ramsay (1986), Golder and Logan (2011), Lalor and McElvaney (2010) (review)
Indicator constructs	
Emotional distress and self-worth	Orth et al. (2008) (review), Orth et al. (2012), Sowislo and Orth (2013)
Emotional distress and perceived financial hardship	Heflin and Iceland (2009), Miech and Shanahan (2000), Muntaner et al. (2004)
Emotional distress and violent events	Golder and Logan (2011) (among women who endorsed substance use)
Sexual self-care and self-worth	El-Bassel et al. (1997), Ethier et al. (2006), Forna et al. (2006), Gutierres and Puymbroeck (2006), Jacobs and Kane (2011), Sterk et al. (2004), Somalai et al. (2000)
Sexual self-care and drug use	Gutierres and Puymbroeck (2006), Sterk et al. (2004), Stockman et al. (2010)
Sexual self-care and violence (not depicted in CLD)[a]	Golder and Logan (2011), Gutierres and Puymbroeck (2006)

[a] Two bivariate relationships included in the model were exclusively informed by the cohort data: HIV-status and perceived financial hardship and the pattern of drug use and drug use. The latter relationship was a function of the modeling (e.g., L2 is only activated for women who are active drug users)

conceptualization of syndemic-risk. In a subsequent literature review, we found that self-worth, defined as a person's evaluation of self and conceptualized as a part of self-esteem (Rosenberg 1979), was independently associated with all of the proposed syndemic constructs (Dietz 1996; Golder and Logan 2011; Logan et al. 2002; Orth et al. 2012; Selenko and Batinic 2011). We returned to review our revised CLD as well as simulated output from six calibrations (scenarios) of our SD model (4 depicted in Fig. 2).

Model Formulation

Model formulation involves translating a CLD into a working simulation tool. For the current project, we used Vensim® modeling software to accomplish this. Model equations are programmed using Vensim's stock-and-flow graphical interface. Equations are formulated to compute rates of change and accumulation over time, and typically include algebraic expressions and/or pre-programmed functions to process information delays, invoke periodic discrete events, or integrate other specified effects.

Information Delays

The information delay was a central structure in equations we used to define key constructs of syndemic risk. In our model, all of our primary constructs, that were not discrete events (i.e., drug use and violent events), could be treated as 'delays in perception,' which are most expediently simulated using an information delay. We used the information delay for all of our major constructs of syndemic risk (i.e., emotional distress, perceived financial hardship, risk of violence, self-worth and sexual self care), with the exception of drug use and violent events, for which we utilized a pre-programmed pulse function. Formulation of each information delay and its parameter values was

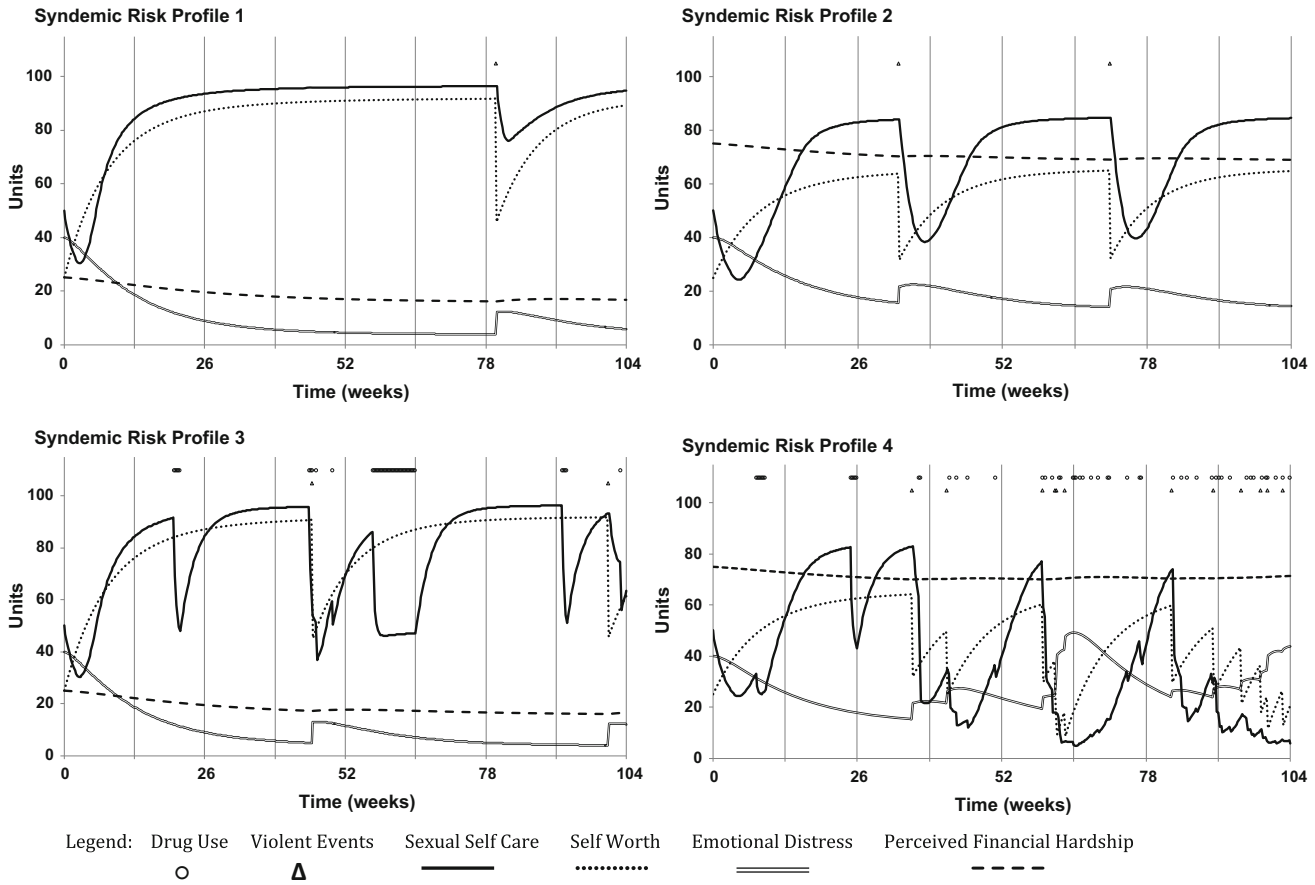

Fig. 2 Simulated scenarios of syndemic risk (1–4)

informed by the three sources of evidence: published literature, trend analyses of our women's cohort data, as well as feedback from the BxCRRB. Further explanation and specifics regarding how we formulated our SD model, including formulation of information delays, are available in (Batchelder and Lounsbury, in press).

Managing Uncertainty of Discrete Events

Although SD models generally simulate continuous processes, as opposed to discrete events, our representation of syndemic risk is linked to specific events, such as a violent incident in the community. We utilized the Vensim pulse train function to manage uncertainty about the probability of occurrence of a discrete event happening. Based on cohort data and literature on substance abuse and violent events among similar populations, including large national samples of frequency of violent events based on previous experience of violence, we developed equations to estimate the pulse rates.

Time Horizon

In the current project, we formulated our SD model to represent the hypothesized behavioral and psychosocial dynamics of an individual woman affected by syndemic risk, over the course of a 2-year period (Time horizon = 104 weeks).

Quantification of Model Constructs

We can classify the constructs included in our model of syndemic risk as endogenous or primary, exogenous, or indicator. Endogenous or primary constructs are those that form a feedback structure, or loop. These include: drug use, violent events, risk of violence, perceived financial hardship, and self-worth. Exogenous constructs are those that have a direct effect on one or more constructs in the model, but are not part of a feedback structure. These include history of childhood sexual abuse, which has a fixed effect on initial self-worth; HIV-status, which has fixed effects on risk of violence and perceived financial hardship; and pattern of drug use, which was programmed to be either a non-user or an active user. When an active pattern of drug use is selected, incidents of drug use vary over time depending on level of self-worth. Like exogenous constructs, indicator constructs are not part of a feedback structure, but can be computed as an outcome of the effect or influence of one or more constructs in the model. These include sexual self-care and emotional distress.

Emotional distress, perceived financial hardship, risk of violence, self-worth, and sexual self-care were all formulated on a 100-point scale, ranging from 0 to 100 units, allowing for ease of comparison of simulated output.

Model Validation Tests

Procedures for SD model-building and validation are organized around the purpose of the model. The validation process occurs as the model is designed, tested and finalized. For the current project, the central validation step was to define and understand the structure and behavior of syndemic risk affecting women with and at-risk for HIV in an impoverished urban community. *Structural validity* involves determining that the model has been formulated with accuracy and adequately represents its intended conceptual description. *Behavioral validity* refers to determining that the model's simulated behavior has sufficient accuracy for its intended purpose. Equally important, and central to the current project, is affirmation of *construct validity*, which ensures that theories and assumptions underlying the conceptual problem, or purpose of the model, are correct and reasonable. Additionally, an evaluation of the type and quality of the sources of evidence available to support model parameterization and calibration, or *data validity*, is also an important aspect of SD model validation (Habbema et al. 2014; Oliva 2003). Data validity involves evaluating whether sufficient information for model formulation and calibration are available, and whether they are adequate and reliable for model evaluation and application (i.e., conducting virtual experiments and policy analyses; J. W. Forrester 1992; Martis 2006).

The structural validity was iteratively assessed, as the model was formulated. This included ensuring that each equation conformed to basic tests of dimensional consistency and was properly initialized and calibrated. Structural validity tests, including parameter values, extreme-condition tests, and dimensional consistency tests were used to confirm that the equations used to construct the model followed commonly accepted mathematical principles, namely that the model was dimensionally valid (i.e., the units of measurement or quantification of the constructs or variables on each side of the equation were the same). The model was then calibrated to ensure replication of associations identified in the literature, consistency with trends derived from the cohort study data and feedback from community stakeholders (BxCRRB).

Results

Our analyses of the dynamics of syndemic risk are summarized in Fig. 1, shown as a CLD. Three causal loops are shown (L1–L3). These loops are comprised of five endogenous constructs (drug use, perceived financial hardship, risk of violence, violent events, and self-worth). Two indicator constructs derived as a function of the feedback structure (emotional distress and sexual self-care). Reported childhood sexual abuse, HIV-status and poverty are included as exogenous inputs, or contextual characteristics or environmental conditions that are not influenced by the SD of focus. These inputs change due to conditions external to the looped (endogenous) dynamics of a social problem of interest.

Feedback Structure Analysis

All three causal loops are reinforcing feedback structures. The first loop (L1) includes self-worth and perceived financial hardship. Incremental changes in one lead to incremental changes in the opposite direction in the other (i.e., as self-worth increases perceived financial hardship decreases and visa versa). This loop is reinforcing as it contains two negative relationships, resulting in a positive or reinforcing feedback structure.

The second loop (L2) involves three syndemic constructs: self-worth, drug use, and violence, which we operationalize as risk of violence and violent events. Given that drug use was conceptualized as a binary construct or initial "switch" (active substance user versus non-user), this loop is only activated when "active substance user" is selected as an initial value. This loop demonstrates that incremental changes in self-worth lead to incremental changes in drug use, in the opposite direction (i.e., as self-worth increases drug use decreases). As drug use increases, risk of violence also increases. As risk of violence increases, the rate of violent events increases. Finally, as violent encounters increase, self-worth decreases.

The third loop (L3) involves four constructs: self-worth, perceived financial hardship, risk of violence and violent events. This structure demonstrates how an incremental change in self-worth leads to an incremental change in the opposite direction in perceived financial hardship (as in L1). It is of note that we are not suggesting that actual financial hardship is caused by level of self-worth; rather, we suggest level of self-worth incrementally contributes to perception of the severity of financial hardship. An incremental change in perceived financial hardship then leads to an incremental change in the same direction in risk of violence (e.g., as perceived financial hardship increases risk of violence increases). An incremental change in risk of violence then leads to an incremental change in the same direction in violent events (e.g., as risk of violence decreases the number of violent events decreases), which then leads to an incremental change in the opposite direction in self-worth (e.g., as the number of violent events increases self-worth decreases).

Emotional distress and sexual self-care are derived effects from the three feedback structures described above, referred to as indicator constructs. Emotional distress is conceptualized as a function of violent events, self-worth and perceived financial hardship. As violent events and perceived financial hardship increase, emotional distress also increases. As self-worth increases emotional distress decreases. Sexual self-care is conceptualized as a function of self-worth and drug use. As self-worth increases sexual self-care also increases. As drug use increases sexual self-care care decreases.

We included three exogenous constructs for which baseline values are set prior to running the model and serve as drivers of selected endogenous constructs. Childhood sexual abuse decreases baseline self-worth. HIV-status and baseline poverty affect both perceived financial hardship and risk of violence. Being HIV + slightly decreases baseline perceived financial hardship (based on the cohort data) and results in higher baseline risk of violence. Poverty is associated with higher perceived financial hardship and initial risk of violence values.

Behavior Pattern Analysis

Based on our three sources of evidence, we formulated the model to simulate various scenarios over 104 weeks (2 years). We first used the model to conduct a preliminary sensitivity analysis, where we simulated output for each construct in our CLD, testing the effects of different values. We examined these results and used them to identify meaningful patterns and dynamics between syndemic constructs.

In order to convey the dynamic variability of syndemic risk, we selected four demonstration scenarios that differ by one socio-environmental construct and one intrapersonal initial variable values: Scenario 1 shows the dynamics of a "non-drug user" with low perceived financial hardship, Scenario 2 shows the dynamics of a "non-drug user" with high perceived financial hardship, Scenario 3 shows the dynamics of an "active user" with low perceived financial hardship and Scenario 4 shows the dynamics of an "active user" with high perceived financial hardship. Initial values for all other endogenous variables and exogenous outputs in the model were not varied for these scenarios. All scenarios presented here did not include an effect of childhood sexual abuse or being HIV+. These scenarios were chosen from a multitude of possible scenarios because they depict patterns seen throughout other model outputs.

We saw consistent patterns including violent events coinciding with decreases in self-worth, sexual self-care and increases in emotional distress across scenarios. Scenarios 3 and 4 are indicative of patterns identified across scenarios including active substance use, in that substance use coincided with decreases in sexual self-care and increases in emotional distress. Further, the interrelationships between violence, drug use, sexual self-care, emotional distress and self-worth became increasingly complex when perceived financial hardship increased, as evidenced in scenarios 2 and 4 compared to 1 and 3, respectively. Additionally, self-worth was a central construct, responding to changes in other constructs across scenarios, as exemplified in all four scenarios. There was substantial variability in the time it took for self-worth and emotional distress to return to initial levels after violent events and substance use occurred across scenarios, demonstrated in the four scenarios in Fig. 2.

Discussion

Our application of SD modeling (1) synthesizes the extant literature, insight from a relevant cohort study and stakeholder feedback related to the ecological factors contributing to syndemic risk among women with and at-risk for HIV; and (2) uses a demonstration SD model to convey how the identified constructs comprising syndemic risk are dynamically interrelated. Applying a SD approach enabled us to build upon findings from prior statistical modeling studies by effectively synthesizing multiple sources of evidence, including feedback from community members that led to inclusion of self-worth as central element of syndemic risk. Our final demonstration model is offered as a tool to improve our understanding of how the identified syndemic constructs are interrelated, in order to explore syndemic theory and strategies for concurrently addressing these dynamic processes. Moving forward, this and other SD models can be used to explore multicomponent multilevel intervention strategies to address syndemic risk.

Presented as feedback loops and as simulated patterns of change over time, our model shows the interdependencies among socio-environmental, interpersonal and intrapersonal level constructs in a manner that supports the importance and utility of applying an ecological framework to the study of complex psychosocial phenomena. The patterns simulated by the model convey and expand on the proposed *synergy* between syndemic problems and their impact on women living with and at risk of HIV poor urban communities (Singer 1996; Meyer et al. 2011). While a multitude of scenarios are possible by varying any of the syndemic constructs, the four scenarios we presented convey patterns seen throughout our model outputs. For example, violent events were consistently followed by change in intrapersonal, including behavioral and psychosocial sequela (e.g., reductions in sexual self-care and self-worth and increases in emotional distress). Generally, the simulated patterns we saw across scenarios were

consistent with published literature (e.g., Catalano et al. 2009; El-Bassel et al. 2005; Jewkes 2002; Meyer et al. 2011; NYC DOMHM 2013; Smith and Romero 2010).

The features of the SD methodology offer unique insights into dynamic patterns beyond what can be gleaned from purely statistical methods based on the general linear model, such as structural equation modeling and path analysis. These benefits include the iterative integration of feedback over a simulated period of time, accounting for the rate of change of variables as well as linkages between equations. We believe this project makes an important contribution to the syndemic literature by demonstrating that we were able to effectively use calculus and algebraic equations to build and validate a SD model utilizing three sources of evidence to simulate syndemic risk among an identified population.

Given the capacity of SD methodology to be consistent with a range of epistemologies, from logical empiricism to relativist, constructivist, and perspectivism philosophies of science, SD modeling projects are a promising way to conduct stakeholder engaged research. This was illustrated by our ability to incorporate the perspectives and lived experiences of community members serving on the BxCRRB (Trickett and Beehler 2013). Their community-level insight enriched our understanding of how to define and explore syndemic risk. Specifically, the BxCRRB members identified self-worth as a highly relevant construct and a potential point of leverage (Kellogg Foundation 2005), which we confirmed was associated with all of the initially identified syndemic problems (e.g., Dietz 1996; Jacobs and Kane 2011; Sowislo and Orth 2013). Based on our second literature review, we now hypothesize it to be in the causal pathways linking the initial syndemic constructs together, as indicated in the CLD (Fig. 1). The involvement of BxCRRB in our study exemplifies how key stakeholders and qualitative methods can strengthen the SD modeling process. This is consistent with calls for greater support of research strategies that emphasize relational processes in which knowledge is generated via cycles of reflective exchange and deliberation among researchers and public stakeholders (Tebes et al. 2014).

Consistent with systems theory, the interrelationships between the identified syndemic constructs indicate a need for multi-level intervention strategies that concurrently target interrelated problems (Trickett and Beehler 2013). To date, few interventions have concurrently focused on addressing intrapersonal, interpersonal and socio-environmental problems (e.g., substance abuse, distress, and financial hardship; Trickett and Beehler 2013; Logan et al. 2002). Interventions that include elements of drug treatment while addressing risk factors such as traumatic stress and low self-esteem have demonstrated efficacy in reducing engagement in high-risk behaviors (Amaro et al. 2007; Exner et al. 1997). This model emphasizes the potential utility of SD as a tool for development and simulated assessment of such interventions.

Together, our conceptualization of syndemic risk, inclusive of self-worth, emphasizes the need to cultivate resilience and ultimately empowerment within women with and at-risk for HIV, consistent with Brodsky and Cattaneo's transconceptual model of empowerment and resilience (2013). We propose that Brodsky and Cattaneo's (2013) emphasis on the need to start with intrapersonal resilience, or the process that leads to adaptive outcomes, in contexts where the disparity between reality and needed change is great (e.g., women with and at-risk for HIV) may be a way to increase self-worth within the presented CLD. According to this theory, initial focus on intrapersonal resilience enables individuals to adapt, withstand or resist negative or risky patterns and be more equipped to successfully pursue empowerment goals in the future. After resiliency has been cultivated, providers can work with individual women to shift power dynamics that impact their current life contexts (e.g., pursuing economic empowerment or seeking safe housing away from an abusive partner). For example, a multi-level intervention that first improves self-worth and focuses on substance use, thus building resiliency, and subsequently works to increase economic freedom (e.g., through housing or vocational training), thus building empowerment, may be more effective than addressing intrapersonal after or concurrently with interpersonal and socio-environmental (Brodsky and Cattaneo 2013). Notably, this theory does not preclude others from working toward systematic shifts in empowerment opportunities through advocating for policy, structural and system changes to reduce social and economic disparities and hardship. We believe this and other SD models can be used to assess the dynamic effects and unintended consequences of multi-component and multi-level intervention strategies, including adjusting the order of simulated treatment effects (e.g., James et al. 2003; Trickett and Beehler 2013).

In order to effectively implement multicomponent multi-level interventions, multidisciplinary partnerships are needed between clinicians, public health and community practitioners, researchers and policy makers (Smith and Romero 2010). In addition to medical providers, clinical and community psychologists, social workers and counselors can play an important role in reducing interrelated intrapersonal, interpersonal and socio-environmental level problems (Carter et al. 2013). Case management, housing support, and gender-specific programming have also helped women with and at-risk for HIV improve access to social services and health care (Kenagy et al. 2003).

While multicomponent multilevel interventions may seem cost-prohibitive, the SD methodology includes feedback structures that integrate equations over time,

enabling cost-benefit analysis of complex interventions without the resources necessary for longitudinal studies. This and other SD models can be used to simulate the effects and cost of different multicomponent multilevel interventions over time.

This work has several limitations. To be as parsimonious as possible while meeting the goal of the model, we simplified our problem conceptualization (Homer and Hirsch 2006); nonessential contextual and historical qualifications were excluded. Therefore, we opted to exclude several potentially relevant constructs based on limited effect identified in our three sources of evidence (e.g., race did not have a significant impact on the syndemic constructs in the cohort sample and was, therefore, removed). While the three sources of evidence adequately informed the model's structure and the bivariate relationships, including enough longitudinal data to calculate rates of change, longitudinal data with shorter intervals between data points, such as momentary ecological assessment, would enable a more precise understanding of the dynamics of syndemic risk. Further empirical work is needed to evaluate the longitudinal relationships between self-worth and the other syndemic constructs. This sample may not be generalizable beyond women with and at-risk for HIV in the Bronx. Additionally, the cohort study's inclusion criteria of previous engagement in HIV-related high-risk behavior may have resulted in a lack of variability among the cohort. Future work is needed to simulate the effects of multicomponent and multilevel intervention strategies to assess the potential benefits, unintended consequences and cost.

Conclusion

As human behavior and psychology are complex and therefore never perfectly predictable, SD modeling is one methodology that can help provide insights about general behavioral patterns or tendencies. Our work shows how SD modeling is a distinctively flexible tool for exploring and understanding social and behavioral complexity in public health and community research projects, beyond what general linear modeling has demonstrated. Additionally, our work provides evidence that SD has the potential to aid in the development of strategies for designing and implementing multicomponent multilevel interventions that strategically address socio-environmental, interpersonal and intrapersonal level problems. Future work is needed to continue to identify the best intervention strategies for reducing the synergistic burden on this vulnerable population, and SD modeling has the potential to play a critical role.

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References

Adler, N. E., Epel, E. S., Castellazzo, G., & Ickovics, J. R. (2000). Relationship of subjective and objective social status with psychological and physiological functioning: preliminary data in healthy white women. *Health Psychology, 19*(6), 586–592.

Amaro, H., Larson, M. J., Zhang, A., Acevedo, A., Dai, J., & Matsumoto, A. (2007). Effects of trauma intervention on HIV sexual risk behaviors among women with co-occurring disorders in substance abuse treatment. *Journal of Community Psychology, 35*, 895–908.

Arriola, K. R. J., Louden, T., Doldren, M. A., & Fortenberry, R. M. (2005). A meta-analysis of the relationship of child sexual abuse and HIV risk behavior among women. *Child Abuse and Neglect, 29*, 725–746.

Bagley, C., & Ramsay, R. (1986). Sexual abuse in childhood: psychosocial outcomes and implications for social work practice. *Journal of Social Work and Human Sexuality, 4*, 33–47.

Batchelder, A.W. & Lounsbury, D. (in press). Simulating syndemic risk: Using system dynamics modeling to understand psychosocial challenges facing women living with and at-risk for HIV. In Zachary P. Neal (Eds.), *Handbook of applied systems science.* New York: Routledge.

Brier, J., & Runts, M. (1993). Childhood sexual abuse: Long-term sequelae and implications for psychological assessment. *Journal of Interpersonal Violence, 8*, 312–330.

Brodsky, A. E., & Cattaneo, L. B. (2013). A transconceptual model of empowerment and resilience: divergence, convergence and interactions in kindred community concepts. *American Journal of Community Psychology, 53*, 333–346.

Bronfenbrenner, U. (1979). *The ecology of human development: experiments by nature and design*. Cambridge, MA: Havard University Press.

Campbell, A. N., Tross, S., Dworkin, S. L., Hu, M. C., Pavlicova, M., & Nunes, E. V. (2009). Relationship power and sexual risk among women in community-based substance treatment. *Journal of Urban Health, 86*(6), 951–964.

Carter, A. J., Bourgeois, S., O'Brien, N., Abelsohn, K., Tharao, W., Greene, S., & CHIWOS Research Team. (2013). Women-specific HIV/AIDS services: Identifying and defining the components of holistic service delivery for women living with HIV/AIDS. *Journal of the International AIDS Society, 16*, 17433.

Catalano, S., Smith, E., Snyder, H. & Rand, M. (2009). Bureau of justice statistics, Selected Findings. Female victims of violence. Published September, NCJ 228356. Accessed 19 September 2012.

Centers for Disease Control and Prevention (2013) HIV surveillance report, 2011; vol. 23. http://www.cdc.gov/hiv/topics/surveillance/resources/reports/. Published February 2013. Accessed 28 August 2014.

Cook, J. A., Grey, D. D., Burke-Miller, J. K., Cohen, M. H., Vlahov, D., Kapadia, F., & Levine, A. M. (2007). Illicit drug use, negative affect and their association with highly active antiretroviral therapy in HIV-positive women. *Drug and Alcohol Dependence, 89*, 74–81.

Coyne, J. C. (1994). Self-reported distress: Analog or ersatz depression? *Psychological Bulletin, 116*(1), 29–45.

Crosby, R. A., DiClemente, R. J., Salazar, L. F., Wingood, G. M., McDermott-Sales, J., Young, A. M., & Rose, E. (2013). Predictors of consistent condom use among young African American women. *AIDS and Behavior, 17*, 865–871.

Dietz, B. E. (1996). The relationship of aging to self-esteem: The relative effects of maturation and role accumulation. *International Journal of Aging and Human Development, 43*, 249–266.

El-Bassel, N., Gilbert, L., Rajah, V., Foleno, A., & Frye, V. (2000). Fear and violence: Raising the HIV stakes. *AIDS Education and Prevention, 12*, 154–170.

El-Bassel, N., Gilbert, L., Witte, S., Wu, E., & Chang, M. (2011). Intimate partner violence and HIV among drug-involved women: contexts linking these two epidemics—challenges and implications for prevention and treatment. *Substance Use and Misuse, 46*, 295–306.

El-Bassel, N., Gilbert, L., Wu, E., Go, H., & Hill, J. (2005). HIV and intimate partner violence among methadone-maintained women in New York City. *Social Science and Medicine, 61*, 171–183.

El-Bassel, N., Schilling, R. F., Irwin, K. L., Faruque, S., Gilbert, L., Von Bargen, J., et al. (1997). Sex trading and psychological distress among women recruited from the streets of Harlem. *American Journal of Public Health, 87*(1), 66–70.

Ethier, K. A., Kershaw, T. S., Lewis, J. B., Milan, S., Niccolai, L. M., & Ickovics, J. R. (2006). Self-esteem, emotional distress and sexual behavior among adolescent females: inter-relationships and temporal effects. *Journal of Adolescent Health, 38*(3), 268–274.

Exner, T. M., Seal, D. W., & Ehrhardt, A. A. (1997). A review of HIV interventions for at-risk women. *AIDS and Behavior, 1*, 93–124.

Forna, F. M., Fitzpatrick, L., Adimora, A. A., McLellan-Lemal, E., Leone, P., & Greenberg, A. (2006). A case-control study of factors associated with HIV infection among black women. *Journal of the National Medical Association, 98*(11), 1798–1804.

Forrester, J. W. (1971). *Principles of systems* (2nd ed.). Cambridge: Wright-Allen Press.

Forrester, J. W. (1992). Policies, decisions, and information sources for modeling. *European Journal of Operational Research, 59*(1), 42–63.

Gielen, A. C., Ghandour, R. M., Burke, J. G., Mahoney, P., McDonnell, K. A., & O'Campo, P. (2007). HIV/AIDS and intimate partner violence: Intersecting women's health issues in the United States. *Trauma Violence Abus, 8*(2), 178–198.

Golder, S., & Logan, T. K. (2011). Cumulative victimization, psychological distress, and high-risk behavior among substance-involved women. *Violence and Victims, 26*, 477–495.

Gonzalez-Guarda, R. M., Florom-Smith, A. L., & Thomas, T. (2011). A syndemic model of substance abuse, intimate partner violence, HIV infection, and mental health among Hispanics. *Public Health Nursing, 28*(4), 366–378.

Gutierres, S. E., & Puymbroeck, V. C. (2006). Childhood and adult violence in the lives of women who misuse substances. *Aggression and Violent Behavior, 11*, 497–513.

Habbema, J. D. F., Wilt, T. J., Etzioni, R., Nelson, H. D., Schechter, C. B., Lawrence, W. F., & Feuer, E. J. (2014). Models in the development of clinical practice guidelines. *Annals of Internal Medicine, 161*, 812–818.

Heflin, C. M., & Iceland, J. (2009). Poverty, material hardship and depression. *Social Science Quarterly, 90*(5), 1051–1071.

Hirsch, G. B., Levine, R., & Miller, R. L. (2007). Using system dynamics modeling to understand the impact of social change initiatives. *American Journal of Community Psychology, 39*(3–4), 239–253.

Homer, J. B., & Hirsch, G. B. (2006). System dynamics modeling for public health: background and opportunities. *American Journal of Public Health, 96*, 452–458.

Howard, A., Floris-Moore, M., Arnsten, J. H., Santoro, N., Fleischer, N., Lo, Y., & Schoenbaum, E. (2005). Disorders of glucose metabolism in HIV-infected women. *Clinical Infectious Diseases, 40*(10), 1492–1499.

Jacobs, R. J., & Kane, M. N. (2011). Psychosocial predictors of self-esteem in a multiethnic sample of women over 50 at risk for HIV. *Journal of Women and Aging, 23*, 23–39.

James, S. E., Johnson, J., Raghavan, C., Lemos, T., Barakett, M., & Woolis, D. (2003). The violent matrix: A study of structural, interpersonal, and intrapersonal violence among a sample of poor women. *American Journal of Community Psychology, 31*(2), 129–141.

Jewkes, R. (2002). Intimate partner violence: Causes and prevention. *Lancet, 359*, 1423–1429.

Kellogg Foundation. (2005). *Racial and ethnic health disparities: Schools of public health respond as engaged institutions.* 75th Anniversary Workshop. Cambridge, MA: Abt Associates.

Kenagy, G. P., Links, N. L., Bruce, D., Warnecke, R., Gordon, A., Wagaw, F., & Densham, A. (2003). Service utilization, service barriers, and gender among HIV-positive consumers in primary care. *AIDS Patient Care STDs, 17*, 235–244.

Lalor, K., & McElvaney, R. (2010). Childhood sexual abuse, links to later sexual exploitation/high-risk sexual behavior, and prevention/treatment programs. *Trauma Violence and Abuse, 11*(4), 159–177.

Lane, S. D., Rubinstein, R. A., Keefe, R. H., Webster, N., Cibula, D. A., Rosenthal, A., & Dowell, J. (2004). Structural violence and racial disparity in HIV transmission. *Journal of Health Care for the Poor and Underserved, 15*, 319–335.

Leary, M. R., & Baumeister, R. F. (2000). The nature and function of self-esteem: Sociometer theory. *Advances in Experimental Social Psychology, 32*, 1–62.

Logan, T. K., Cole, J., & Leukefeld, C. (2002). Women, sex, and HIV: Social and contexual factors, meta-analysis of published interventions, and implications for practice and research. *Psychological Bulletin, 128*, 851–885.

Lounsbury, D. W., Hirsch, G. B., Vega, C., & Schwartz, C. E. (2014). Understanding social forces involved in diabetes outcomes: A system science approach to quality-of-life research. *Quality of Life Research, 23*(3), 959–969.

Lounsbury, D. W., & Mitchell, S. G. (2009). Introduction to special issue on social ecological approaches to community health research and action. *American Journal of Community Psychology, 44*(3), 213–220.

Lounsbury, D. W., Schwartz, B., Palma, A., & Blank, A. (2015). Simulating patterns of patient engagement, treatment adherence, and viral suppression: A system dynamics approach to evaluating HIV care management. *AIDS Patient Care STDs, 29*, S55–S63.

Lundberg, J., & Kristenson, M. (2008). Is subjective status influenced by psychosocial factors? *Social Indicators Research, 89*, 375–390.

Mabry, P. L., Olster, D. H., Morgan, G. D., & Abrams, D. B. (2008). Interdisciplinary and systems science to improve population health: A view from the NIH office of behavioral and social sciences research. *American Journal of Preventive Medicine, 35*, S211–S224.

Martis, M. (2006). Validation of simulation based models: A theoretical outlook. *The Electronic Journal of Business Research Methods, 4*(1), 39–46.

Mendenhall, E. (2015). Beyond comorbidity: A critical perspective of syndemic depression and diabetes in cross-cultural contexts. *Medical Anthropology Quarterly,*. doi:10.1111/maq.12215.

Meyer, J. P., Springer, S. A., & Altice, F. L. (2011). Substance abuse, violence, and HIV in women: A literature review of the syndemic. *Journal of Women's Health, 20*, 991–1006.

Miech, R. A., & Shanahan, M. J. (2000). Socioeconomic status and depression over the life course. *Journal of Health and Social Behavior, 41*(2), 162–176.

Miller, R. L., Levine, R. L., McNall, M. A., Khamarko, K., & Valenti, M. T. (2011). A dynamic model of client recruitment and retention in community-based prevention programs. *Health Promotion Practice, 12*(1), 135–146.

Milstein, B. (2008). Hygeia's constellation: Navigating health futures in a dynamic and democratic world. Center for Disease Control, Syndemic Prevention Network. http://www.cdc.gov/syndemics/monograph/sections/systemdynamics.htm. Accessed 14 October 2012

Muntaner, C., Eaton, W. W., Miech, R., & O'Campo, P. (2004). Socioeconomic position and major mental disorders. *Epidemiologic Reviews, 26*, 53–62.

Mustanki, B., Garofalo, R., Herrick, A., & Donenberg, G. (2007). Psychosocial health problems increase risk for hiv among urban young men who have sex with men: Preliminary evidence of a syndemic in need of attention. *Annals of Behavioral Medicine, 34*(1), 37–45.

New York City Department of Health and Mental Hygiene. (2013). Epiquery: NYC interactive health data system—community health survey 2013. Retrieved from http://nyc.gov/health/epiquery. Accessed 25 May 2015

Oliva, R. (2003). Model calibration as a testing strategy for system dynamics models. *European Journal of Operational Research, 151*, 522–568.

Orth, U., Robins, R. W., & Roberts, B. W. (2008). Low self-esteem prospectively predicts depression in adolescence and young adulthood. *Journal of Personality and Social Psychology, 95*, 695–708.

Orth, U., Robins, R. W., & Widaman, K. F. (2012). Life-span development of self-esteem and its effects on important life outcomes. *Journal of Personality and Social Psychology, 102*, 1271–1288.

Palma, A., Lounsbury, D.W., Schlecht, N.F. & Agalliu, I. (in press). A system dynamics model of serum prostate-specific antigen screening for prostate cancer. *American Journal of Epidemiology*.

Pitpitan, E. V., Kalichman, S. C., Eaton, L. A., Cain, D., Sikkema, K. J., Watt, M. H., & Pieterse, D. (2013). Co-occurring psychosocial problems and HIV risk among women attending drinking venues in a South African township: A syndemic approach. *Annals of Behavioral Medicine, 45*, 153–162.

Radloff, L. S. (1977). The CES-D scale: A self-report negative affect scale for research in the general population. *Applied Psychological Measurement, 1*, 386–401.

Richardson, G. P. (1991). *Feedback thought in social science and systems theory*. Waltham, MA: Pegasus Communications Inc.

Richardson, G. P. (1998). Problems in causal loop diagrams revisited. *System Dynamics Review, 13*, 247–252.

Richardson, G. P., & Pugh, A. L. (1981). *Introduction to system dynamics modeling with DYNAMO*. Cambridge, MA: MIT Press.

Rosenberg, M. (1979). *Conceiving the self*. New York, NY: Basic Books.

Schiff, M., El-Bassel, N., Engstrom, M., & Gilbert, L. (2002). Psychological distress and intimate physical and sexual abuse among women in methadone maintenance treatment programs. *Social Service Review, 76*, 302–320.

Selenko, E., & Batinic, B. (2011). Beyond debt. A moderator analysis of the relationship between perceived financial strain and mental health. *Social Science and Medicine, 73*, 1725–1732.

Simoni, J. M., & Ng, M. T. (2000). Trauma, coping, and negative affect among women with HIV/AIDS in New York City. *AIDS Care, 12*, 567–580.

Singer, M. (1996). A dose of drugs, a touch of violence, a case of AIDS: conceptualizing the SAVA syndemic. *Free Inquiry in Creative Sociology, 24*, 99–110.

Smith, L., & Romero, L. (2010). Psychological interventions in the context of poverty: participatory action research as practice. *American Journal of Orthopsychiatry, 80*, 12–25.

Somalai, A. M., Kelly, J. A., Heckman, T. G., Hackl, K., Runge, L., & Wright, C. (2000). Life optimism, substance use, and AIDS-specific attitudes associated with HIV risk behavior among disadvantaged innercity women. *Journal of Women's Health and Gender-Based Medicine, 9*, 1101–1111.

Sonis, J., & Langer, M. (2008). Risk and protective factors for recurrent intimate partner violence in a cohort of low-income inner-city women. *Journal of Family Violence, 23*, 529–538.

Sowislo, J. F., & Orth, U. (2013). Does low self-esteem predict depression and anxiety? A meta-analysis of longitudinal studies. *Psychological Bulletin, 139*, 213–240.

Stall, R., Mills, T. C., Williamson, J., Hart, T., Greenwood, G., Paul, J., & Catalnia, J. A. (2003). Association of co-occurring psychosocial health problems and increased vulnerability to HIV/AIDS among urban men who have sex with men. *American Journal of Public Health, 93*, 939–942.

Sterk, C. E., Klein, H., & Elifson, K. W. (2004). Predictors of condom-related attitudes among at-risk women. *Journal of Women's Health, 13*(6), 676–688.

Stockman, J. K., Campbell, J. C., & Celentano, D. D. (2010). Sexual violence and HIV risk behaviors among a nationally representative sample of heterosexual American women: The importance of sexual coercion. *Journal of Acquired Immune Deficiency Syndromes, 53*(1), 136–143.

Tebes, J. K., Thai, N. D., & Matlin, S. L. (2014). 21st century science as a relational process: From eureka! to team science and a place for community psychology. *American Journal of Community Psychology, 53*, 475–490.

Testa, M., Livingston, J. A., & Leonard, K. E. (2003). Women's substance use and experiences of intimate partner violence: A longitudinal investigation among a community sample. *Addictive Behaviors, 28*, 1649–1664.

Trickett, E. J., & Beehler, S. (2013). The ecology of multilevel interventions to reduce social inequalities in health. *American Behavioral Scientist, 57*(8), 1227–1246.

Trochim, W. M., Cabrera, D. A., Milstein, B., Gallagher, R. S., & Leischow, S. J. (2006). Practical challenges of systems thinking and modeling in public health. *American Journal of Public Health, 96*(3), 538–546.

U.S. Census Bureau. (2010). *American Community Survey*. Retrieved 5 April 2015, from http://www.census.gov/acs/www/about_the_survey/american_community_survey_and_2010_census/.

Ventana Systems, Inc. Vensim®: Simulator for Business, Ventana Systems Inc.. Retrieved at June 17, 2011, from Open Educational Resources (OER) Portal at http://www.temoa.info/node/5591

Ward, M. C. (1993). A different disease: HIV/AIDS and health care for women in poverty. *Culture, Medicine and Psychiatry, 17*, 413–430.

Wolstenholme, E. F. (1983). System dynamics: A system methodology or a system modelling technique. *Dynamica, 9*(II), 84–90.

Zierler, S., & Krieger, N. (1997). Reframing women's risk: social inequalities and HIV infection. *Annual Review of Public Health, 18*, 401–436.