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Article

An agent-based simulation of persistent inequalities in health behavior: Understanding the interdependent roles of segregation, clustering, and social influence

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ABSTRACT

Health inequalities are conspicuously persistent through time and often durable even in spite of interventions. In this study, I use agent-based simulation models (ABMs) to understand how the complex interrelationships between residential segregation, social network formation, group-level preferences, and social influence may contribute to this persistence. I use a more-stylized ABM, Bubblegum Village (BV), to understand how initial inequalities in bubblegum-chewing behaviors either endure, increase, or decrease over time given group-level differences in preferences, neighborhood-level barriers or facilitators of bubblegum chewing (e.g., access to bubblegum shops), and agents' preferences for segregation, homophily, and clustering (i.e., the 'tightness' of social networks). I further use BV to understand whether segregation and social network characteristics impact whether the effects of a bubblegum-reduction intervention that is very effective in the short term are durable over time, as well as to identify intervention strategies to reduce attenuation of the intervention effects. In addition to BV, I also present results from an ABM based on the distribution and social characteristics of the population in Philadelphia, PA. This model explores similar questions to BV, but examines racial/ethnic inequalities in soda consumption based on agents' social characteristics and baseline soda consumption probabilities informed by the 2007–2010 National Health and Nutrition Examination Survey. Collectively, the models suggest that residential segregation is a fundamental process for the production and persistence of health inequalities. The other major conclusion of the study is that, for behaviors that are subject to social influence and that cluster within social groups, interventions that are randomly-targeted to individuals with 'bad' behaviors will likely experience a large degree of recidivism to pre-intervention behaviors. In contrast, interventions that target multiple members of the same network, as well as multilevel interventions that include a neighborhood-level component, can reduce recidivism.

1. Introduction

1.1. Diet inequalities

Racial/ethnic minorities suffer from high rates of obesity and related chronic disease (Flegal, Carroll, Ogden, & Curtin, 2010). While physical (in)activity plays a part, these inequalities are at least partially driven by well-documented differences in diet (Go et al., 2013). High rates of obesity among Mexican Americans (~78%) may, in part, be driven by the high level of consumption of sugar-sweetened beverages (SSB) among that population (Flegal et al., 2010). Between-group differences in consumption of fast food and other foods away from home may also contribute to obesity disparities (Batis, Hernandez-Barrera, Barquera, Rivera, & Popkin, 2011; Boone-Heinonen et al., 2011; Bowman, Gortmaker, Ebbeling, Pereira, & Ludwig, 2004). Improving diet quality is of critical public health importance, but doing so is difficult because diet is influenced by multilevel factors at the environmental (e.g., access to food resources), household (e.g., family composition, income), individual (e.g., educational attainment, preferences), and interpersonal (e.g., social influence) levels (Diez-Roux et al., 1999; Glanz, Sallis, Saelens, & Frank, 2005; Moore, Diez Roux, Nettleton, Jacobs, & Franco, 2009). Addressing inequalities is even more difficult, because racial/ethnic groups vary markedly in many of the characteristics (e.g., age, educational attainment, neighborhood) that most strongly influence diet. For example, the Latino population as a whole is younger, poorer,

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and less well-educated than the White population. Thus, dietary inequalities could be driven by cultural differences (e.g., food preferences), environmental disparities in food access, differences in the group-level distribution of socio-demographic characteristics (i.e., population composition), or some combination thereof. Furthermore, due to the interdependent effects of residential, economic, and school-based segregation, individuals are likely to live, work, and play with others who share their racial/ethnic and economic characteristics. The influence exerted through homogeneous social networks may help consolidate health behaviors and exacerbate inequalities between groups.

1.2. Residential segregation and health

The high level of racial/ethnic and income-based segregation in American cities is well-documented (Massey & Denton, 1988, 1989, 1993). Segregation is associated with poorer educational outcomes (e.g., educational attainment and test scores) and highly concentrated poverty in minority neighborhoods (Card & Rothstein, 2007; Massey, Condran, & Denton, 1987; Massey & Denton, 1993; Massey & Fischer, 2000). This place-based intersection of race/ethnicity and socioeconomic status likely has broad implications for health inequalities, as income and education are widely accepted as fundamental social causes of disease (Link & Phelan, 1995). More proximate mechanisms through which segregation may produce inequalities is via disparities in access to neighborhood resources. This may include both social resources (e.g., neighborhood-level educational attainment or income) as well as physical resources (e.g., the food and physical activity environment, health care services). Most relevant to the current study, low-income and minority neighborhoods tend to have higher concentrations of fast food restaurants, small corner stores, and liquor stores but decreased access to comprehensive supermarkets (Larson, Story, & Nelson, 2009; Morland, Wing, Diez Roux, & Poole, 2002). Several studies have observed a relationship between the local food environment and dietary or weight outcomes, although most of these studies are based on cross-sectional data and there is no consensus on whether this relationship is causal (de Vet, de Ridder, & de Wit, 2011; Holsten, 2009). Among the limited longitudinal studies in this area, Boone-Heinonen and colleagues (2011) found that neighborhood density of fast food restaurants is related to fast food consumption among low-income adults (Boone-Heinonen et al., 2011).

1.3. Clustering of health behaviors and outcomes

Health behaviors and outcomes tend to cluster within social networks. This has most prominently been documented in a series of studies by Christakis, Fowler, and others regarding such diverse health issues as obesity, smoking, alcohol consumption, and happiness (Christakis & Fowler, 2007, 2008; Fowler & Christakis, 2008; Rosenquist, Murabito, Fowler, & Christakis, 2010). As described by Shoham and colleagues (2012), there are three explanations that could each independently produce this type of clustering: (1) individuals could be attracted to others that share their health behaviors and outcomes (i.e., homophily), (2) individuals within a social network may share exposure to environmental, social, cultural or other factors that shape behavior (i.e., common causes), and (3) an individual's behavior may be influenced by the behavior of members of their social networks (i.e., social influence).

Assessing the extent to which each of these three mechanisms contribute to clustering of health behaviors and outcomes is important for understanding disease dynamics at the population level. In the absence of other clustering mechanisms, homophily in and of itself would have little or no impact on inequalities because social network formation would not change within- or between-group distributions of health outcomes. The ‘common causes’ clustering hypothesis is largely consistent with the social determinants and health disparities literature (e.g., the fundamental causes of disease hypothesis of Link and Phelan (1995)). In general, this literature asserts that social gradients in the distribution of ‘upstream’ factors (e.g., income, education, power) are the key drivers of disparities in ‘downstream’ health factors. The social influence hypothesis is consistent with behavioral theory, most prominently Bandura's Social Cognitive Theory (Bandura, 1986). Furthermore, as described in a review of social influence and obesity conducted by Cunningham, Vaquera, Maturo, and Narayan (2012), several longitudinal studies have provided evidence in support of social influence.

If social influence is a driver of clustering, there would be important implications for health inequalities and health promotion interventions. Residential, school-based, and other forms of segregation may result in homogeneous networks across factors like race/ethnicity and income. Against this backdrop of homogeneous social networks, social influence that consolidates health behaviors within groups would likely exacerbate between-group inequalities. A further consequence of social influence may be positive ‘spillover’ effects on the friends and family of those who participate in an intervention (Trogdon & Allaire, 2014). Conversely, social influence may dampen intervention effects over time. Weight loss interventions suggest that maintenance of intervention effects is a challenge for many participants (Wing & Phelan, 2005; Wing, Tate, Gorin, Raynor, & Fava 2006). Such interventions might achieve positive behavior change, but social influence from friends and family may ‘pull’ the participant back to the pre-intervention levels exhibited by his/her social network. If social influence is important, enrolling multiple members of the same social network may be an effective strategy to promote maintenance of intervention effects.

1.4. Complex systems research in diet

A growing body of research has used complex systems methods like agent-based modeling and system dynamics modeling to understand social processes that impact diet and other health behaviors. In brief, complex systems methods are simulation-based approaches that allow researchers to examine the potential impacts of feedback loops, non-linear effects, adaptation, and other dynamic processes that change over the course of time (Mabry, Marcus, Clark, Leischow, & Méndez, 2010). Health researchers, for example, have used agent-based models (ABMs) to examine adaptive behaviors including the spread of health behaviors through social networks via social influence (Hammond & Ornstein, 2014; Orr, Galea, Riddle, & Kaplan, 2014), adaptation of food stores in response to purchasing patterns in a given neighborhood (Auchincloss, Riolo, Brown, Cook, & Diez Roux, 2011), and the impact of past experiences on future behavior (Yang, Roux, Auchincloss, Rodriguez, & Brown, 2011). These mechanistic models seek to identify and understand features of complex systems (e.g., feedback loops, social influence) that contribute to population-level patterns in health behaviors and outcomes. A further body of literature uses complex systems models to identify leverage points for interventions to help practitioners and policymakers decide between one or a combination of interventions (Widener, Metcalf, & Bar-Yam, 2013; Zhang, Giabbanelli, Arah, & Zimmerman, 2014).

1.5. The present study

In this study, I use agent-based models (ABMs) to explore group inequalities in health behaviors. I have two primary objectives: First, I examine the potential implications of residential segregation, social network formation, and social influence for persistence of group inequalities. Second, I explore the durability of interventions to improve health behaviors in the presence of social influence. Broadly, I focus on three types of interventions: those that target random individuals among the minority population, those that target multiple members of the same social network, and those that target the environment.