Preventive Medicine xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Assessing the role of access and price on the consumption of fruits and vegetables across New York City using agent-based modeling

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ARTICLE INFO

Keywords:
Nutrition
Food policy
Urban health
Agent-based modeling
Systems science

ABSTRACT

Most residents in New York City (NYC) do not consume sufficient fruits and vegetables every day. Difficulties with access and high prices of fruits and vegetables in some neighborhoods contribute to different consumption patterns across NYC neighborhoods. We developed an agent-based model (ABM) to predict dietary behaviors of individuals at the borough and neighborhood levels. Model parameters were estimated from the 2014 NYC Community Health Survey, United States Census data, and the literature. We simulated six hypothetical interventions designed to improve access and reduce the price of fruits and vegetables. We found that all interventions would lead to increases in fruit and vegetable consumption but the results vary substantially across boroughs and neighborhoods. For example, a 10% increase in the number of fruit/vegetable vendors combined with a 10% decrease in the prices of fruits and vegetables would lead to a median increase of 2.28% (range: 0.65%–4.92%) in the consumption of fruits and vegetables, depending on neighborhood. We also found that the impact of increasing the number of vendors on fruit/vegetable consumption is more pronounced in unhealthier local food environments while the impact of reducing prices on fruits/vegetable consumption is more pronounced in neighborhoods with low levels of education. An agent-based model of dietary behaviors that takes into account neighborhood context has the potential to inform how fruit/vegetable access and pricing strategies may specifically work in tandem to increase the consumption of fruits and vegetables at the local level.

1. Introduction

Fruit and vegetable consumption is an important part of a healthy diet, and the benefits of reaching the recommended fruit and vegetable consumption level are well documented in recent research. Fruit and vegetable consumption is linked to decreased all-cause mortality and a longer lifespan (Bellavia et al., 2013). In meta-analyses of results from cohort studies, the risk of coronary heart disease and stroke decreased by 4% and 5%, respectively, per portion of fruit and vegetable consumed (Dauchet et al., 2006; Dauchet et al., 2005). Fruit and vegetable consumption has also been shown to reduce blood pressure, an important risk factor for cardiovascular disease (Sacks et al., 2001). As such, multiple health organizations recommend increasing daily fruit and vegetable consumption to prevent many chronic health conditions (Appel et al., 2006).

Despite the health benefits of fruit and vegetable consumption, only one in three women and one in five men report consuming the recommended amount (five or more servings/day) of fruits and vegetables (Blanck et al., 2008). Potassium intake—a marker of fruit and vegetable intake—is also low, with the average adult in the United States (US) consuming about 2600 mg/day, below the recommended adequate intake of 4700 mg/day (Hoy and Goldman, 2013). Although great effort has been made at both the local and national levels, the consumption of fruits and vegetables has not improved in recent years (Moore and Thompson, 2015).

The consumption of fruits and vegetables, and correspondingly,

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http://dx.doi.org/10.1016/j.ypmed.2017.10.014
Received 8 July 2017; Received in revised form 30 September 2017; Accepted 4 October 2017

potassium intake in New York City (NYC), the largest city in the United States, is low (Jack et al., 2013; Loftfield et al., 2013). There are also striking differences in fruit and vegetable consumption across different neighborhoods in NYC; residents in wealthier neighborhoods, such as the Upper East Side, consume more fruits and vegetables than residents of low income neighborhoods, such as the South Bronx (Gordon et al., 2011). These differences in fruit and vegetable consumption as well as in overall diet also overlap with disparities in the prevalence of diabetes (Upper East Side: 4.1%; South Bronx: 20.2%), hypertension (Upper East Side: 21.4%; South Bronx: 35.5%), and obesity (Upper East Side: 12.5%; South Bronx: 34.4%) (New York City Department of Health and Mental Hygiene, 2014).

Access and affordability of fresh produce are two of the most influential factors that contribute to the significant differences in fruit and vegetable consumption across different neighborhoods (Larson and Story, 2015). For instance, 78.3% of Upper East Side residents report living within a five-minute walk or less to fresh produce, while only 47.4% of South Bronx residents report the same (New York City Department of Health and Mental Hygiene, 2014). Similarly, varying levels of poverty mean that affordability of available produce varies greatly; over 40% of South Bronx residents have incomes below the poverty line, while just 7% of Upper East Side residents live below the poverty line (Larson and Story, 2015). Given the fact that disparities in dietary behaviors across advantaged and disadvantaged population groups have been widening over time,(Wang et al., 2014) there is a critical need to understand which interventions are most effective in reducing health disparities among subgroups and across different neighborhoods in NYC.

Although several programs and initiatives have been adopted to increase access (e.g., the addition of mobile fruit and vegetables carts) and reduce costs (e.g., the Supplemental Nutrition Assistance Program, Health Bucks) in NYC,(Sacks et al., 2015) their utilization and impact may be limited due to the lack of tools for systematic program design before the implementation of an initiative. This study combines the best available local data with an innovative systems science approach to generate predictions around the impact of various interventions on fruit and vegetable consumption in NYC. Systems science and systems thinking could provide decision-makers with a better understanding of the relationship between neighborhood factors and the dietary patterns of residents. Agent-based modeling (ABM), a systems science modeling approach specialized in decoding complex processes in which population heterogeneity and dynamic interactions prevail, can greatly complement traditional epidemiologic studies to predict the effect of an intervention under different circumstances or to identify alternate interventions that may result in the desired outcomes (Li et al., 2016a; Li et al., 2016b). We aim to develop and use an ABM to provide new insights on how to increase the consumption of fruits and vegetables in NYC by simulating populations, food consumption decisions, local food environments, interventions, and the complex interactions among these factors in different boroughs and neighborhoods. Specifically, we simulated six hypothetical interventions addressing accessibility (the number of fruit and vegetable vendors) and affordability (the price of fruits and vegetables) of healthy foods across neighborhoods. We also identified important neighborhood factors that may influence the effectiveness of these interventions.

2. Methods

2.1. Model overview

We developed an agent-based model of dietary behaviors based on data from NYC to conduct simulated evaluations of different interventions. In our model, simulated individuals differed by their demographic characteristics (e.g., age, gender, and educational attainment) as well as their taste preferences (whether a person has a strong flavor), health beliefs (whether a person has a strong value for eating healthy), and price sensitivity (whether a person thinks the food costs too much). Individuals were also connected to others in a social network, and the influence of their social connections may change their taste preferences and health beliefs. We only simulated adults in NYC because data for children are not available.

We placed simulated individuals (agents) in a geographic space, either in a borough or a neighborhood in NYC. Individuals' food choices were influenced by their proximity to different food outlets (e.g., supermarkets, fruit and vegetable markets, and limited and full service restaurants). In a simulated day, each agent made a dietary decision based on an empirical probability function that includes variables representing demographic characteristics, health beliefs, taste preferences, food accessibility, and price sensitivity. Health beliefs, taste preferences, and price sensitivity were standardized to be bounded between 0 and 1. Food accessibility was measured by whether an individual could walk to a given type of outlet within a predefined walking distance. We used 0.25 mile as the walking distance. Thus, an individual living within 0.25 mile of a food outlet is given an accessibility of 1 (reachable); otherwise, the accessibility is 0 (unreachable). More details about parameter definition and model structure are included in the online supplemental document. The agent-based model was programmed using the programming language Java.

2.2. Population characteristics and the food environment

We extracted population characteristics for modeling purposes from multiple data sources, including the 2010 US Census, the 2010 NYC Community Health Survey (CHS), the Food Attitudes and Behaviors (FAB) Survey, and several published studies (Li et al., 2016b; New York City Department of Health and Mental Hygiene, 2010; National Cancer Institute, 2015; Powell et al., 2007). The NYC CHS is an annual survey of adults in NYC, providing data on chronic disease conditions and behavioral risk factors (New York City Department of Health and Mental Hygiene, 2010). The FAB Survey measures a variety of factors (e.g., demographics, attitudes, beliefs) related to fruit and vegetable consumption among adults (National Cancer Institute, 2015). We extracted food environment data from the 2010 ZIP Code Business Patterns data (Census Bureau, 2010). Some of the above data sources are at the zip code level, so we also conducted data aggregation to obtain estimates at the neighborhood level. A variety of neighborhood definitions exist in NYC. We used the 34 neighborhoods defined by the United Hospital Fund because they are commonly used for policy analysis (e.g., the NYC CHS uses this definition) (United Hospital Fund, 2015).

2.3. Interventions

We simulated a baseline scenario (prior to hypothetical changes) and six hypothetical interventions that represent: 1) a 10% increase in the number of fruit and vegetable vendors (e.g., mobile fruit and vegetable carts, fruit and vegetable markets), 2) a 20% increase in the number of fruit and vegetable vendors, 3) a 10% reduction in price of fruits and vegetables, 4) a 20% reduction in the price of fruits and vegetables, 5) 10% increase in the number of vendors and 10% decrease in price, and 6) 20% increase in the number of vendors and 20% decrease in price. We predicted the impact of these hypothetical interventions on the proportion of the population who consume two or more servings of fruits and vegetables across the five NYC boroughs (the Bronx, Brooklyn, Manhattan, Queens, and Staten Island) and 34 United Hospital Fund neighborhoods (a full list of these neighborhoods is included in the online supplementary document) in NYC in three years. These hypothetical interventions are designed to test both the separate and combined impacts of improved access and reduced prices of fruits and vegetables on food choices.