Modeling the Transmission Dynamics of Unhealthy Behaviors for Evaluating Resource Allocation Strategies in Obesity Prevention

Research Problem:
The worldwide growth in overweight and obesity has created negative health, social and economic consequences for children, adults, and society as a whole.\textsuperscript{1-3} In the US, alongside increasing adult rates, children have also seen a significant growth and spread of overweight and obesity in the past several decades.\textsuperscript{4,5} Some research indicates increases in US childhood overweight and obesity rates may be slowing,\textsuperscript{5} but concerns remain on how to accelerate a downward trend in order to abate the obesity-related health and economic consequences.\textsuperscript{6} Research is needed to better understand the complex dynamics of social spread of obesity among children via both peer and adult influences in order to identify key leverage points to guide policy and direct the optimum mix of prevention and treatment resources.

The immediate cause of overweight and obesity is energy imbalance, but complex interactions of multi-level factors including individual human biology, behavior, and environment give rise to the worldwide epidemic we currently see.\textsuperscript{7} Christakis and Fowler (2007) performed a study, in which they found that the adult obesity epidemic appears to be spreading through social ties, and this conclusion is made based on the clustering of surveyed individuals according to their BMIs and quantifying the increased chance of becoming obese based on different ties.\textsuperscript{8} Other research provides additional evidence that strengthens the role of social influence in both adult and child populations, and mechanisms of social norms, capital (i.e., resources, information and people accessible through a social network), and stress are thought to be key pathways which transfer obesity risk.\textsuperscript{9}

Research has shown adult to adult\textsuperscript{8}, adult to child\textsuperscript{10-14}, and child to child\textsuperscript{14-18} influence in terms of obesity and obesity-related attitudes, norms, and behaviors (i.e., nutrition and physical activity). Linear thinking and modeling provide limited understanding of the ways these multiple influences interact and interdepend to cause the spread of overweight and obesity. Complex systems modeling provides a methodology to better model and understand these influences to enhance our ability to identify key leverage points to target finite resources for optimum impact.

Research Objective:
The objective of this paper is to construct and validate a system dynamics model of the social transmission of behaviors that cause childhood overweight and obesity through adult and peer influence, and use the model to test combinations of prevention and treatment interventions at adult and child levels in order to determine leverage points for informing policy decisions that aim at reducing childhood obesity rates.

Background:
System dynamics modeling has been applied to the dynamics of obesity in prior research. These models inform this research; however, to our knowledge no other models have
addressed the specific problem of multiple-level social transmission of behaviors that cause overweight and obesity in children from both peers and adults.

Obesity models have been used to understand weight at individual and biological level by modeling the dynamics of energy regulation to understand issues such as weight cycling. Other research via system dynamics in the field has built upon the individual models in order to capture the energy and weight balance through the life course of individuals and aggregate this to population level trends. These models were used to test and formulate information about policy interventions, but do not explicitly account for the social transmission of obesogenic behaviors. Other models have attempted to do this through integrating agent-based models using opinion-dynamics with system dynamics models. The agent-based framework presented in Karanfil et al. (2010) has great value for the understanding of explicit mechanism of transference via opinion but does not consider the different dynamics and mechanisms embedded within adult-to-child and child-to-child social ties. For example, adults may socially transfer obesity risk to children via mechanisms other than opinion such as direct control of children’s eating and physical activity behaviors and provision of resources that enable or constrain behaviors.

Previous research has used mathematical models to understand the growth of obesity via social transmission. Evangelista et al (2004) used parameters of peer pressure to become a fast food eater to model changes in overweight and obesity rates. Similar models were built to model population obesity rate growth in Spain for different age groups including infants and adults, and used to discuss and test interventions aimed at prevention or treatment. These models provide a useful framework to understand and model social transference of obesity; however, these models do not provide functionality to understand different levels of influence on children from their peers and adults.

**System Dynamics:**
System dynamics modeling is needed to understand the multi-level social influences on the spread of child obesity risk. It is clear that obesity has grown and spread in both adult and child populations, but the interdependencies among parent and peer influences on childhood obesity is difficult to understand using linear models. A system dynamics model can better capture these relationships, and provide a methodology to test the plausible impact configurations of prevention and treatment interventions directed towards adults and children may have on childhood obesity trends.

**Model Description:**
Figure 1 provides a causal loop diagram depicting the aspect of child and adult social transmission of overweight and obesity.

**Model Boundaries:** The model boundary includes social transference of risk at adult-to-adult, adult-to-child, and child-to-child levels. The transmission is assumed to occur through social influences on food consumption and physical activity behaviors via norms, attitudes, behaviors,
and provision of interpersonal material and physical structures and resources. The model considers factors of individual human biology and high level physical and material resources (e.g., built environment, accessibility of resources, etc.) beyond the system boundaries.

The elements of the system include the compartments specific to individuals health status related to weight, i.e., normal weight, overweight, and obese adults and similarly normal weight, overweight, and obese children. The levels of each of these elements influence the social transmission of overweight and obesity; adult levels influence adult-to-adult and adult-to-child transmission, and child levels influence child-to-child. In this research we assume child-to-adult transmission of these behaviors are negligible. In order to consider the dynamics of interventions in terms of the issue of social transmission, the causal loop diagram also includes variables of demand for child and adult prevention and treatment interventions. The levels of overweight and obese children and adults influence the demand for treatment interventions, respectively. Similarly, the levels of normal weight children and adults influence the demand for prevention interventions. Demand is linked to provision of respective interventions (i.e., child obesity prevention, child overweight and obesity treatment, adult obesity prevention, and adult overweight and obesity treatment). The child and adult obesity treatment interventions influence the respective level of overweight and obese children and adults actively engaging in dieting and physical activity to lose weight. Finally, the system includes an element of finite resources available to distribute to the overweight and obesity prevention and treatment interventions.

**Feedback Loops:** Due to the social transmission of overweight and obesity, reinforcing loops between normal weight individuals, social transmission of peer to peer unhealthy behaviors, and overweight and obesity individuals exist for both adults and children (see Figure 1). There are two reinforcing loops seen in both the adult and child populations: (1) a loop between the increase in overweight and obesity that leads to an increase in social transmission and (2) a loop from the increase in overweight and obesity that leads to a decrease in normal weight, which leads to a subsequent increase in social transmission.

The additional consideration of demand for prevention and treatment interventions with the provision of mentioned interventions also create four balancing loops. The increase in both child and adult overweight and obesity leads to an increased demand for child and adult treatment interventions respectively, the demand increases the rate of providing said interventions, which leads to greater rates of overweight and obesity children and adults dieting and doing physical activity, and thus a subsequent decrease in overweight and obese populations. Similarly loops are seen in the demand for prevention interventions based on the normal weight populations. The rate of providing prevention interventions is shown to decrease the social transmission of overweight and obesity from adult to adult, adult to child, and child to child.

**Dynamical Hypotheses and Insights:** This paper hypothesizes that the multi-level and variable degree of social transmission of overweight and obesity from adult-to-adult, adult-to-child, and child-to-child can create different patterns of overweight and obesity. The research expects to
gain insight related to the appropriate mix of prevention and treatment interventions targeted toward adult and child to create optimum decreases in childhood obesity levels.

**Methodological Approach**

We build a stock and flow diagram to model the underlying structure, and governing equations of the model are adapted from previous models. Preliminary diagrams shown in Figure 2 and 3, indicate stocks of normal, overweight, and obese adults and children respectively with flows in-between.

Model parameters are identified using existing US surveillance system data and research literature. Stock variables are parameterized with rates from NHANES to identify rates of normal, overweight and obesity in adults and children following current BMI and percentile guidelines. NHANES and other similar national surveillance sources (e.g., NHIS, BRFSS, and YRBS) are used to identify needed trends of flow between overweight and obese status as well as rates of dieting, exercise, and average time to lose weight for obese and overweight adults and children actively trying to lose weight. Finally, existing literature is used to provide coefficients for adult-adult, adult-child, and child-child social transmission. We also attempt to estimate a parameter to model the differences in contact rates between and among adults and children.

We use Vensim to simulate the model and test the dynamic hypotheses and assumptions. Previous trends in obesity rates can be used to test model sensitivity. Finally we test different policies of prevention and treatment interventions by varying model parameters of social transmission and overweight and obesity physical activity and dieting rates. Different combinations of adult and child obesity prevention and treatment alone and in combination with each other are tested.

**Noted Challenges and Limitations**

In this project we need to find appropriate data from the current evidence-base that matches with needed parameters. More evidence has been collected on social transmission rates in recent years, but this parameter may be difficult to ascertain. Additionally, coefficients of social transmission that exist are noted for limited ability to delineate social versus biological and environmental risks.

Using a system dynamics model will provide insight into plausible impact on overweight and obesity rates; however, assumptions are made (e.g., homogeneous mixing of the population) that have weaknesses when fit with the realities of social ties. Further assumptions will also need to be made regarding the impact and influence of dieting and exercise on overweight and obese groups that do not take into account the influence of biology and genetics.
Figure 1. Causal Loop Diagram of Adult and Child Social Transmission of Overweight and Obesity
Figure 2. Stock and Flow Diagram of Child Overweight and Obesity

Figure 3. Stock and Flow Diagram of Adult Overweight and Obesity
REFERENCES


