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Modeling the influence of social networks and environment on energy balance and obesity

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ABSTRACT

The influence of social networks on the development of obesity has been demonstrated, and several models have been proposed. However, these models are limited since they consider obesity as a 'contagious' phenomenon that can be caught if most social contacts are deemed obese. Furthermore, social networks were proposed as a means to mitigate the obesity epidemic, but the interaction of social networks with environmental factors could not yet be explored as it was not accounted for in the current models. We propose a new model of obesity to face these limitations. In our model, individuals influence each other with respect to food intake and physical activity, which may lead to changes depending on the environment, and will impact energy balance and weight. We illustrate the potential of our model via two questions: could we focus on social networks and neglect environmental sources of influence, at least from a modelling viewpoint? Are some social structures less prone to be influenced by their environment? We performed a factorial analysis based on both synthetic and real-world social networks, and found that the environment was a key component behind changes in weight but its contribution was mitigated by structural properties of the population. Furthermore, the contribution of the environment was not dictated by macro-level properties (small-world and scale-free), which suggests that particular patterns of social ties at the micro-level are involved in making populations more resilient to change and less influenced by the environment.

1. Introduction

Increasing evidence has shown that the health of individuals is connected [38], which can be intuitively understood as friends who share activities such as dieting or exercising will also share a part of their health outcome. This was illustrated in a recent review by Hammond who found social influence to be a significant factor in obesity [33]. This review concluded that we need to better understand the interplay of social influences with other factors driving obesity, and that computational simulation represent "one especially promising approach" to help foster our understanding. In this paper, we propose a computational model to investigate the interplay of social and environmental influences.

Several computational models have been proposed to understand the role of social influence in obesity [4,35]. However, they only took a simplistic approach by considering that individuals directly spread their weight (*e.g.*, if one person has a majority of obese friends then he would simply turn obese). In this paper, we propose a new model of obesity, motivated by the fact that obesity results from a long-term imbalance between physical activity and food intake, and that these two factors are influenced by peers [8,11,22,39]. In our model, individuals are not directly acting on others' weights but rather influencing social norms regarding food and physical activity, which contribute to changes in weight. Furthermore, our model accounts for the fact that one is not only influenced by peers when making a decision about an activity such as exercising: the environment shapes the possible choices. This includes the physical (built) environment, which may limit the offer of places to exercise, and the norms conveyed by the media which contribute to decision making.

Bahr et al. concluded from their model that traditional interventions may fail because they do not take into account the impact of social networks [4]. This raises questions: could we focus on social networks and neglect environmental sources of influence, at least from a modelling viewpoint? Are some social structures less prone to be influenced by their environment? We illustrate the potential of our model by using it to investigate these questions, both for synthetic populations and a real-world population.

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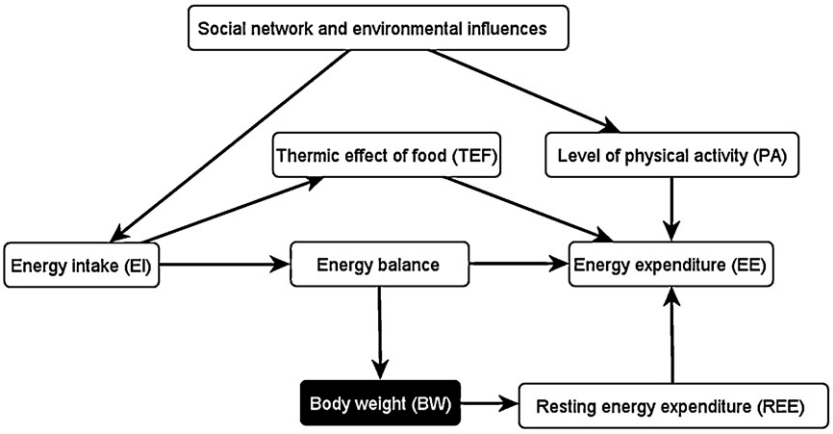

Fig. 1. Core model relationships. Social network and environmental factors are modeled as influencing energy intake and the level of physical activity. Energy expenditure is the sum of the thermic effect of food, resting energy expenditure, and the level of physical activity. Energy intake and energy expenditure determine the energy balance which in turn determines body weight.

1.1. Contribution of the paper

The principal contributions of the present work can be summarized as follows:

- We developed a model of obesity that accounts for social and environmental influences on food and physical activity, instead of a majority vote directly determining obesity as in previous models.
- We applied the model to investigate the relative contributions of social and environmental influences on the obesity epidemic, both for synthetic populations generated using known features of social networks (small-world and scale-free) and a real-world network.
- Our results suggest that the environment cannot be neglected, but its importance depends on the connections between individuals. In other words, the social ties of friendship are structured in different ways across populations, and these structures affect the sensitivity of a population to its environment. Some populations can be more cohesive, leading to a lower change on weight and being less prone to change based on the environment. The cohesiveness of a population is not a simple function of its high-level properties but may depend on structural features that remain to be investigated.

1.2. Organization of the paper

In Section 2, we focus on the processes unfolding on social networks: how individuals influence each other regarding food and physical activity. The principles of our model are first introduced intuitively, and then the mathematical specification is developed. In Section 3, we turn to using this process on social networks, both synthetically generated and extracted from a real-world sociological study. The motivating question is to investigate the contributions of social and environmental influences to obesity, that is, by monitoring changes on average weight. For both cases, we derive from a literature review representative values for initial weight, and we use previous research to assign values for initial physical activity. In synthetic populations, we explain how individuals are connected, and we detail the procedure that assigns meaningful values to the model's parameters in order to perform a factorial design (*i.e.*, identify the contribution of different influences). The same design is applied to a real-world population, and we compare the contribution of social and environmental influences in these different settings. Finally, we discuss the limitations of this model, due in part to gaps in our current understanding of obesity.

2. Model

2.1. Informal description

At the level of the individual, we explicitly model the main components of metabolism, as shown in Fig. 1. Whether an individual gains or loses weight depends on the balance between energy intake (*EI*) and energy expenditure (*EE*). When this balance (*EI*–*EE*) is positive, the energy surplus leads to an increase in body weight (*BW*). Similarly, if the balance is negative, then there is a loss in body weight. Energy expenditure is modeled as a function of three components: an individual's level of physical activity (*PA*), his resting energy expenditure (*REE*) and the thermic effect of food (*TEF*). *REE* is a function of the percentage of lean and fat mass which we approximated as a fixed percentage of body weight. *TEF* was assumed to be 10% of EI [14] and *PA* contributes to the calculation of energy expenditure as a multiplier of resting energy expenditure.

Both *EI* and *PA* in an individual are influenced by a combination of social network and environmental factors. The social network influence on an individual's physical activity or energy intake is the sum of the difference between the individual and each of his friends, normalized by the total number of friends. The social network influence is then combined with the influence of the environment, and if the resulting influence is sufficient (*i.e.*, above a set threshold), then an impact is exerted upon the individual (Fig. 2). The mechanism of a threshold and a corresponding impact models a simple decision-making process. If the model of an individual's action was to also include beliefs and previous experience, then an agent-based framework should be employed in lieu of the network framework used here. However, data may be currently too limited to allow for a richer decision-making process, as outlined in the Discussion. The mechanism proposed here aims at capturing a broad array of situations found in real-life, as exemplified in the following case.

If an individual who is not physically active is surrounded by active friends, then the influence of his social network will be great. If the individual also lives in an environment that promotes physical activity, then the combined influence of the individual's social network and environment is likely sufficient to trigger an impact on physical activity. However, the environment may also inhibit physical activity in which case the threshold may not been reached and the individual's level of physical activity remains unchanged.