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Exploring walking differences by socioeconomic status using a spatial agent-based model

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Abstract

We use an exploratory agent-based model of adults' walking behavior within a city to examine the possible impact of interventions on socioeconomic differences in walking. Simulated results show that for persons of low socioeconomic status, increases in walking resulting from increases in their positive attitude towards walking may diminish over time if other features of the environment are not conducive to walking. Similarly, improving the safety level for the lower SES neighborhoods may be effective in increasing walking, however, the magnitude of its effectiveness varies by levels of land use mix, such that effects of safety are greatest when persons live in areas with a large mix of uses.

Keywords

agent-based model; walking; socioeconomic status

Introduction

It is well established that lower socioeconomic status (SES) is associated with lower levels of physical activity (Ford et al., 1991; Gidlow et al., 2006; Mackenbach et al., 2008).

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Walking is increasingly recognized as an important component of physical activity which can be easily incorporated into daily life, and is potentially amenable to interventions. Among US urban adults, lower SES persons tend to walk more for transportation and walk less for recreation than higher SES persons (Besser and Dannenberg, 2005; Kruger et al., 2008; Pucher and Renne, 2003). SES differences in walking are likely to emerge from the dynamic interplay of individual and environmental factors (Ball et al., 2007; Cerin et al., 2009; Kamphuis et al., 2009). A better understanding of the factors driving SES differences in walking could shed light on strategies not only to reduce SES disparities in physical activity but also to improve population levels of walking generally.

Agent-based models (ABMs) are computational models that can be used to simulate the dynamic interactions of agents and environment in order to gain understanding of the functioning of the system (Axtell and Epstein, 1994; Bonabeau, 2002). An advantage of ABMs over statistical models is they account for feedbacks between agents and between agents and environments over time. It has been argued that ABMs may be of use in the investigation of how dynamic processes shape the distribution of health outcomes (Auchincloss and Diez Roux, 2008; Galea et al., 2009).

We use a previously developed exploratory ABM of adults' walking behavior (Yang et al., 2011) to examine the possible impact of interventions on socioeconomic differences in overall walking and in walking for different purposes. We examine the impact of combinations of two strategies commonly proposed as ways to increase walking, and their interactions: improving people's attitudes towards walking (an individual-targeted intervention, for example through health education campaigns) and improving safety (a social environment intervention, for example through community policing efforts). In order to further illustrate how the model can be used to explore interactions between different types of interventions, we explore whether the impact of these is modified by mixed land use (a feature of the physical environment).

This study's intent was to assess possible impacts of certain types of interventions rather than to make specific predictions. We use a simplistic exploratory model and like all models, conclusions are contingent on assumptions encoded in the model. However, we believe our assumptions are reasonable based on current knowledge and the model replicates key patterns observed in the real world.

Research method

Details of the model are provided elsewhere (Yang et al., 2011). Briefly, the model represents a hypothetical city of 108,000 adults and locations are placed within a grid space. Each individual is assigned properties such as SES, attitude towards walking, home and work location. Individuals perform activities such as traveling to work, for shopping, and for recreation. Whether an individual walks is a function of distance to different activities, walking ability, and attitude towards walking. An individual's attitude towards walking evolves over time through several feedbacks including prior walking experiences (e.g., the safety level of the walking route and number of walking trips that cross the walking route), and attitudes of the other individuals within her/his social network. Parameters such as probabilities and maximum walking distances for different activities were calibrated using data from 2001 National Household Travel Survey (NHTS, 2001)

Previous work (Yang et al., 2011) identified one scenario which generated SES differences in walking that were relatively consistent with the ones most commonly observed in empirical data (Besser and Dannenberg, 2005; Kruger et al., 2008; Pucher and Renne, 2003). In this scenario (subsequently referred to as the baseline scenario), the city is divided into five concentric zones. There is perfect segregation by SES, such that the lowest SES

residents live in the core (Zone 1) and the SES of residents increases from the core to the periphery (Zone 5). The density of non-residential locations such as worksites or amenities for shopping and recreation decays outwards with the ratio of 0.5 from one zone to another. Safety levels increase outwards from Zone 1 (lowest safety value of 1) to Zone 5 (highest safety value of 5). Unless noted, at inception the model assumes no differences in attitude towards walking across SES groups.

We compared a total of 12 scenarios labeled BS_x, AS_x, ES_x and DS_x where x can be 1, 3 or 5. BS1 (B for baseline) is the baseline scenario described above. BS3 and BS5 modify the safety level of the core area (zone 1) only: in BS3 the safety level is increased to an intermediate level (value=3) and in BS5 the safety level is increased to the highest level (value=5). Scenarios AS_x (A for attitude) are similar to BS_x, except that the attitude towards walking of the lowest SES persons (SES1) is increased so that at inception, the lowest SES residents have a preference for walking that is twice as high as the other SES groups. Because the mean walking attitude for the population as a whole is assumed to be constant, this implied that the attitude for the other SES groups was decreased slightly. In order to further examine how land use modified the impacts of changes in safety we also developed scenarios ES_x (E for even) and DS_x (D for decay) which modify the land-use distribution of the baseline scenario: in ES_x non-residential density is assumed to be even across zones; in DS_x the density of non-residential uses decays outwards with a ratio of 1/3 in order to create more pronounced differences in land use than in the baseline scenarios.

Results are based on the values measured on day 10,000 and averaged across 10 simulations. Day 10,000 was selected because prior work (Yang et al., 2011) suggested that SES differences in walking had achieved an approximate equilibrium after this point.

Results

Figure 1 shows total walking trips per person per day, and Figure 2 shows walking trips per person per day for different purposes: for work, for basic needs (including grocery and other shopping and visiting social places) and for recreation.

In the baseline scenario BS1 (upper left, Figure 1), the mean number of daily walking trips per person was about 0.25–0.26 and was not patterned by SES. Increasing safety in the lowest SES areas, however, substantially changed this pattern such that the lowest SES persons walked substantially more than higher SES persons in scenario BS3 and BS5 (compare across first row of Figure 1). In contrast, increasing the attitude towards walking in the lowest SES groups had no impact (compare first and second rows in Figure 1). When non-residential densities were evenly distributed (third row, Figure 1) the lower SES groups walked less than the higher SES groups, but SES differences were reduced when safety in the core (Zone 1) was high (compare ES3, ES5 to ES1 row three Figure 1). More extreme differences in land-use further accentuated SES differences in walking observed in the BS scenarios (compare top and bottom rows, Figure 1), i.e., lowest SES groups walked substantially more than higher SES groups even in the DS1 scenario).

The impact of improving safety in the lowest SES areas on increases in walking in the lowest SES group was greater when land-use mix was very unequally distributed (bottom row, Figure 1) and smaller when land-use mix was evenly distributed (third row, Figure 1). Analogously, increasing mixed land use in the core resulted in substantial increases in walking among the lowest SES group, and this effect was greatest when safety in the core was high (compare walking for low SES groups across rows 3 (no differences in mixed use) and 4 (extreme differences in mixed use) for the leftmost and rightmost columns).

The patterns observed for walking for basic needs were very similar to those observed for total walking (Figure 2b) partly because walking for basic needs represents a substantial share of all walking trips. However, important differences were observed for walking to work and walking for recreation. Lower SES persons walked more to work than higher SES persons across all scenarios although the SES gradients were substantially weaker and almost absent when land-use mix was evenly distributed (Figure 2a, third row). Walking for recreation was consistently higher in the higher SES groups than in the lower SES groups, but this gradient became less pronounced as safety in the low SES areas increased (Figure 2c, compare across columns). Differences in land-use had virtually no impact on walking for recreation (compare rows 3 and 4 of figure 2c).

Figure 2 also shows that increasing attitude towards walking in the lower SES groups had no impact on any type of walking (compare first and second rows). Increasing safety in the core increased walking in the lowest SES groups for all scenarios and all types of walking (compare across columns). However effects of increases in safety on walking to work and for basic needs were largest when mixed land use in the core was also high (bottom row figures 2a and 2b).

Discussion

The simulation results suggest that the walking increases resulting from increasing a positive attitude towards walking diminish over time if other features of the environment (such as safety) are not conducive to walking. This is consistent with research suggesting that the long-term maintenance of the effects of individual-based physical activity interventions is challenging (Müller-Riemenschneider et al., 2008). Another finding is that although increasing the safety level for lower SES neighborhoods may be effective in increasing walking, the magnitude of its effectiveness varies by the patterns of land-use mix.

In the baseline scenario, attitudes towards walking were equal across SES groups at inception. However, the positive attitude towards walking decreased in the lower SES persons but increased in the higher SES persons over time. This occurred because of both the differential exposure to safety by SES and the feedbacks from walking experiences to walking attitude. Any SES differentials in attitude at inception were overcome by these feedback mechanisms operating over time.

In addition, safety and land-use mix acted synergistically such that the effect on walking among lower SES groups of one was magnified in the presence of the other. When the concentration of non-residential uses in the core was low the chance that a low SES person would find a suitable location within walking distance was also low, and the effect of safety on walking was diminished because the probability that persons would be exposed to the higher safety through walking was lower, hence the feedback to attitude had a lower chance to operate. The opposite occurred when mixed land use was high in low SES areas.

It is important to note that these simulations are based on a stylized exploratory model and are meant to illustrate the types of insights that can be obtained from these approaches. Drawing reliable conclusions about the predicted impact of interventions in a particular setting would require many model refinements and incorporation of additional data to support the assumptions in the model. Whenever possible, conclusions regarding impacts of interventions should be confirmed in experimental designs. In this exploratory model, land-use mix and safety were selected as examples of features of the built and social environments which have been linked to walking in prior work (Yang et al., 2011). Many other factors and dynamics that may contribute to walking were not included. Future modifications can include, for example, incorporation of a public transportation system as

well as the inclusion of long-term influences of walking patterns on subsequent changes in the built and social environments.

A major challenge is making these models empirically grounded given that data to support some parameters may be unavailable or may be impossible to obtain. Nevertheless they can yield insights into basic dynamics that are not obtainable using other approaches. Together with other methods, including observational studies as well as quasi experiments and trials, ABMs may contribute to providing the evidence base necessary to improve population levels of walking and reduce inequalities in walking.

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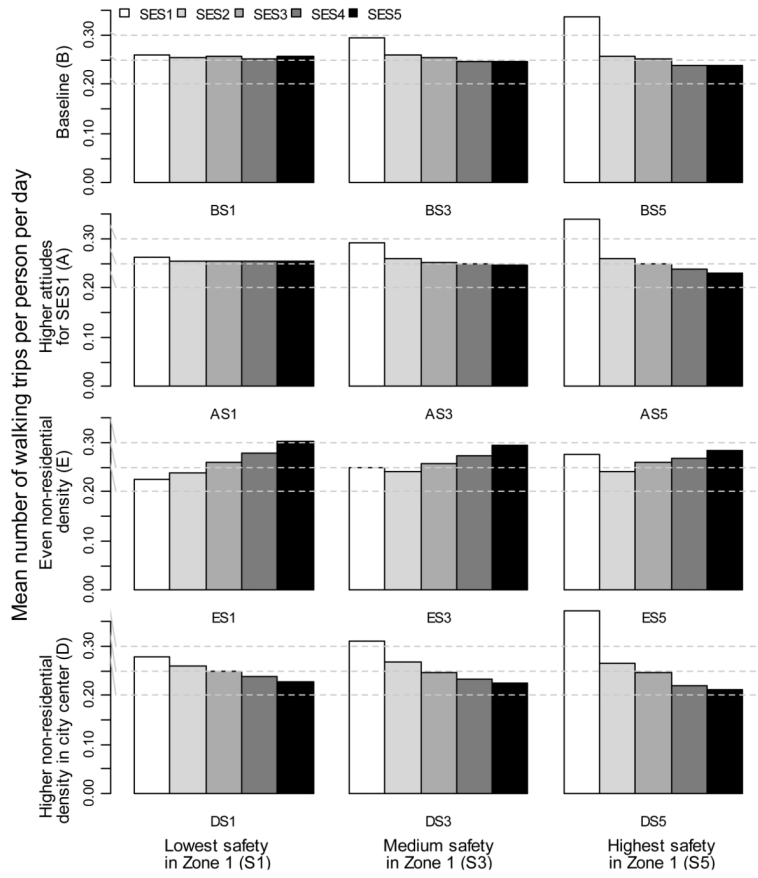


Figure 1. Mean number of walking trips per person per day for five socio-economic status (SES) groups for various scenarios as described in the text.

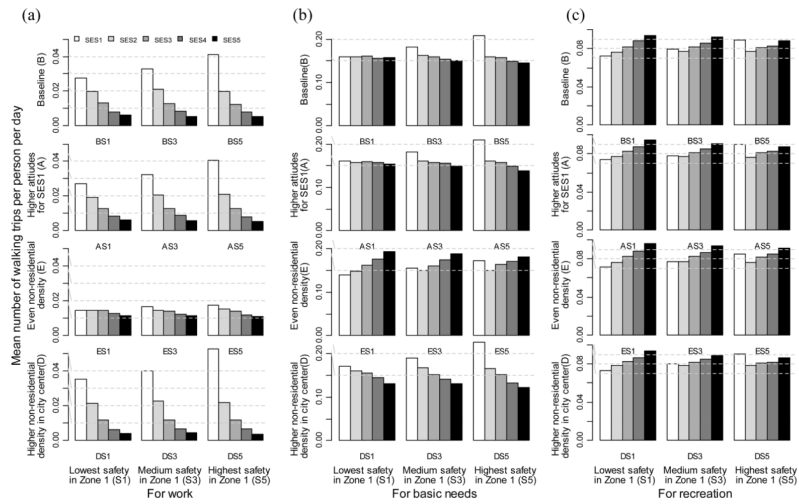


Figure 2. Mean number of walking trips per person per day to work (a), for basic needs (b) and for recreation (c) for five socio-economic status (SES) groups for different scenarios as described in the text.