



Simulating the Impact of Crime on African American Women's Physical Activity and Obesity

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Objective: The objective of this study was to quantify the impact of crime on physical activity location accessibility, leisure-time physical activity (LTPA), and obesity among African American women.

Methods: An agent-based model was developed in 2016 to represent resource-limited Washington, DC, communities and their populations to simulate the impact of crime on LTPA and obesity among African American women under different circumstances.

Results: Data analysis conducted between 2016 and 2017 found that in the baseline scenario, African American women had a 25% probability of exercising. Reducing crime so more physical activity locations were accessible (increasing from 10% to 50%) decreased the annual rise in obesity prevalence by 2.69%. Increasing the probability of African American women to exercise to 37.5% further increased the impact of reducing crime on obesity (2.91% annual decrease in obesity prevalence).

Conclusions: These simulations showed that crime may serve as a barrier to LTPA. Reducing crime and increasing propensity to exercise through multilevel interventions (i.e., economic development initiatives to increase time available for physical activity and subsidized health care) may promote greater than linear declines in obesity prevalence. Crime prevention strategies alone can help prevent obesity, but combining such efforts with other ways to encourage physical activity can yield even greater benefits.

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Additional Supporting Information may be found in the online version of this article

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Introduction

African American women report the lowest rates of leisure-time physical activity (LTPA) (1-4) and have the highest obesity prevalence in the United States (5) as well as an increased risk for cardio-metabolic diseases, including diabetes and coronary artery disease. A disproportionate number of African Americans live in urban, resource-limited areas (i.e., communities with lower neighborhood-level socioeconomic status and fewer resources for physical activity [PA] and healthy nutrition), where neighborhood crime has emerged as a potential correlate with out-of-home PA and obesity (6,7). However, connecting neighborhood crime changes to health behaviors and subsequent outcomes is difficult. Methodological limitations exist for cross-sectional or variable-based studies quantifying neighborhood crime's impact on LTPA (8-10). Moreover, existing studies do not adequately account for complex interactions between individual- and environmental-level factors in the neighborhood crime and LTPA relationship. Therefore, we developed an agent-based model (ABM) to simulate individuals' actions and their interactions with the environment, specifically African American women's LTPA practices in low-resource settings. Given the significant resources required for public health interventions to increase LTPA, the ABM allows for testing potential interventions before implementation.

Our experiments quantified the impact of varying the effects of individual- and neighborhood-level factors (including crime) on PA location accessibility, LTPA, and obesity among a population of African American women, aged 18 to 65, living in the three lowest-median-income neighborhoods, or wards, of Washington, DC's eight wards (11).

Methods

Model structure

Our Virtual Population Obesity Prevention Lab, a geospatially explicit ABM developed in 2016 in Python, includes virtual representations of households, PA and crime locations, and African American women (age 18-65) living in Washington, DC, Wards 5, 7, and 8. Each agent has various characteristics, including age, height, lean/fat mass, and household location and income. Each agent also has an embedded metabolic model converting caloric intake and expenditure to corresponding lean/fat mass (12,13). Supporting Information Table S1 provides additional assumed agent characteristics for the model.

Figure 1 illustrates the model structure, and Supporting Information Table S1 also provides model assumptions and data sources. Each agent has a baseline probability to exercise. This captures the agent's current desire to exercise and includes factors such as household financial and employment status, family/caregiving responsibilities, chronic health conditions, weather, social group influence, and broader social pressures including density of and relatability to exercisers in the community (14-18). The agent decides where to engage in LTPA based on a gravity model, which considers LTPA locations within an agent's transport radius from home (0.5 miles if walking (19); 2.5 miles if driving.) There are three location types where agents can engage in LTPA: home, outdoor locations (pools, parks, bike trails and lanes), or municipal recreational centers. Outdoor locations and recreational centers match real geographic locations within Washington, DC. We excluded commercial gym facilities as there are none

in Ward 8. If an agent is unable to select a suitable location, she does not exercise. Lastly, an agent decides on LTPA duration and intensity. The probability of PA intensity (moderate vs. vigorous) and duration differs based on whether the agent exercises at home or out-of-home (Figure 1). Caloric expenditure from exercise is determined by LTPA intensity, duration, and the agent's current body weight (20).

Crime parameters affecting exercise decisions

We assume that crime affects LTPA decisions by reducing PA location accessibility when crime occurs at or near PA locations or on the agent's travel path to the location (21). Crime events are represented in the model at a given time and date, by a specific type (violent vs. property), and at a given location. We calculated the crime's impact on LTPA accessibility based on three crime parameters: radius, duration, and effect (Figure 1). "Radius" represents the agent's LTPA locations within the specific radial distance from the crime origin that is affected by the crime; "duration" represents the amount of time the crime affects an agent; and "effect" represents a decrease in the probability that agents will travel through or exercise in areas affected by the crime. Multiple crimes occurring on the agent's travel path or at the LTPA location have an additive effect (e.g., for a LTPA location where two crimes' radii overlap during the same duration, and each crime has a 20% reduction effect, there will be a combined 40% reduction that agents will use that LTPA location).

Data sources

Residential and sociodemographic data about the study population came from a synthetic population developed by Wheaton et al. (22) and from US Census Bureau Public Use Microdata Sample files and Census aggregate data. Initializing fat and lean mass data and ranges for LTPA intensity came from the 2013-2014 National Health and Nutrition Examination Survey (23). LTPA duration range data came from prior analyses evaluating time-use data (20). Our model used historical 2014 Washington, DC, crime surveillance data based on the DC Metropolitan Police Department's crime report database (24). Baseline probability to exercise was established from self-reported PA data from African American women aged 18-65 living in Wards 5, 7, and 8 from the Washington, DC, Cardiovascular Health and Needs Assessment (DC-CHNA), a community-based participatory research project (25).

Experimental scenarios

We examined three experimental scenarios in 2016 and 2017, varying agents' baseline exercise probability. Baseline probabilities reflect population-level calculations of varied likelihoods of exercising.

Scenario 1 (baseline scenario): Crime's impact on LTPA and obesity prevalence at baseline probability (25%) to exercise. Our baseline scenario (scenario 1) is based on data collected from the DC-CHNA population (26), wherein we estimated that the baseline exercise probability is approximately 25%, and includes individual, social, and environmental characteristics, such as family and employment commitments, that might influence one's decision to exercise.

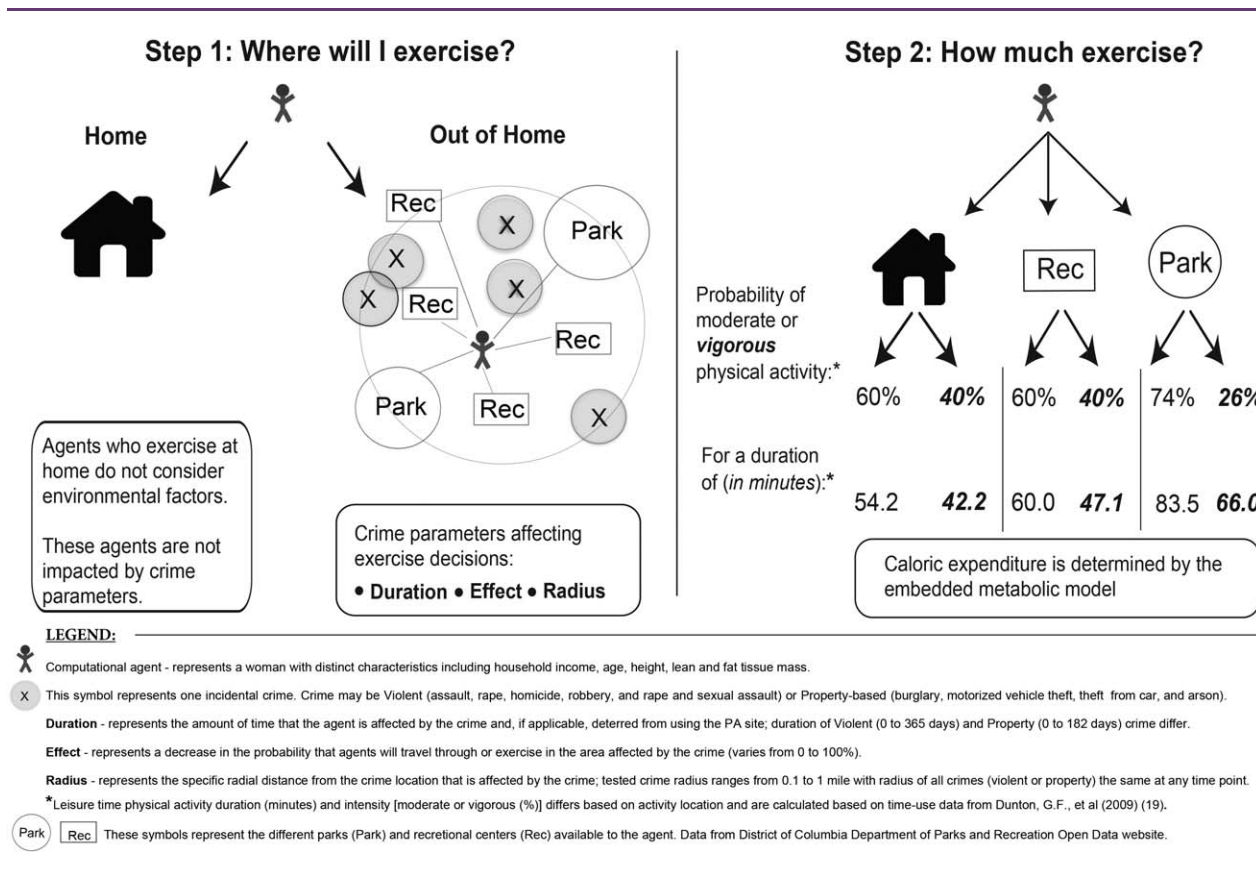


Figure 1 Model diagram.

Scenario 2: Crime's impact on LTPA and obesity prevalence at increased probabilities (37.5% and 50%) to exercise. In scenario 2, we increased baseline probability to exercise from 25% to 37.5% and 50%. This allowed us to examine hypothetical, but feasible, circumstances wherein agents' baseline exercise probability increases from changes in non-crime-related factors (e.g., decreasing financial barrier to exercise).

Scenario 3: Isolated impact of crime reduction on LTPA and obesity prevalence. In scenario 3, we increased baseline exercise probability to 100%. While we recognize this is highly unlikely, this scenario allowed us to isolate effects of reducing crime on LTPA.

We also tested experimental scenarios varying the radius, duration, and effect of crime.

Validation

We validated our model by comparing the proportion of women exercising daily based on our simulation to DC-CHNA survey data (25,27) and the proportion of women with obesity in our model to Behavioral Risk Factor Surveillance System data (Centers for Disease Control and Prevention-conducted survey on US residents' health-related risk behaviors and chronic health conditions) (28)

for Washington, DC. We also tested the validity of our model under extreme conditions. For an extended description, see Supporting Information. This study was approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB #00004203).

Results

Figure 2 illustrates the percent of women exercising daily for each scenario; as crime's impact diminished, LTPA location accessibility increased. Figure 3 illustrates changes in overweight and obesity prevalence for each scenario over a year when 10%, 50%, and 90% of LTPA locations were accessible. We selected these values because they represent a set of anthropomorphic outcomes through the range of accessible LTPA locations to identify trends in the relationship between LTPA and anthropomorphic outcomes.

Scenario 1 (baseline): Crime's impact on LTPA and obesity prevalence at baseline probability (25%) to exercise

In the baseline scenario, there was a moderate increase in the proportion of women engaging in LTPA on a given day as LTPA

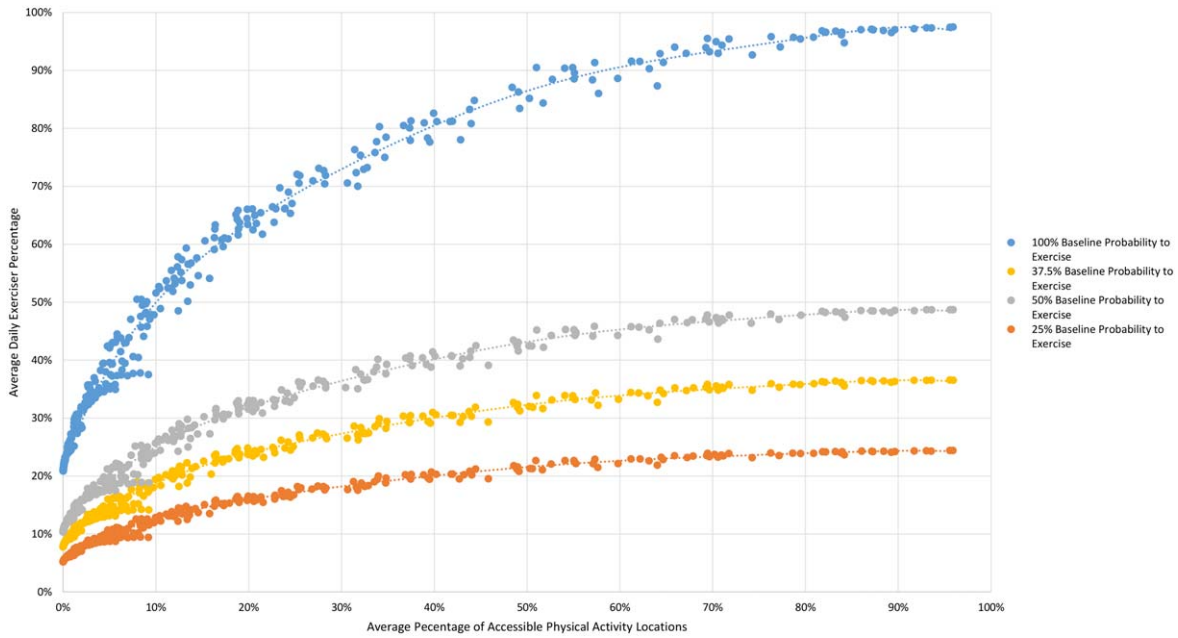


Figure 2 Average daily exercise percentage by average percentage of accessible physical activity locations.

location accessibility increased because of to reduced crime impact. Our model predicted that when only 10% of LTPA locations were accessible, on average, 13.08% (95% CI: 13.07-13.09) of women exercised per day, yielding a 2.94% (95% CI: 2.88-3.00) annual obesity prevalence increase. When crime reductions led to 50% of LTPA locations being accessible, 21.28% (95% CI: 21.27-21.29) of women engaged in LTPA on any given day, resulting in a 0.25% (95% CI: 0.2-0.3) annual increase in the proportion of women with obesity. Finally, when 90% of LTPA locations became accessible because of crime reductions, 24.23% (95% CI: 24.22-24.25) of women engaged in LTPA on any given day, resulting in an annual

0.79% reduction (95% CI: 0.74-0.84) in the proportion of women with obesity.

Scenario 2: Crime’s impact on LTPA and obesity prevalence at increased probabilities (37.5% and 50%) to exercise

At 37.5% baseline exercise probability, when only 10% of LTPA locations were accessible, on average, 19.62% (95% CI: 19.61-19.63) of women exercised per day, yielding a 1.05% (95% CI: 1.01-1.09) annual increase in the proportion of women with

Change in Overweight and Obesity Prevalence Over One Year				Change in Obesity Prevalence Over One Year			
Baseline Probability to Exercise	Percent of Accessible Physical Activity Locations			Baseline Probability to Exercise	Percent of Accessible Physical Activity Locations		
	10%	50%	90%		10%	50%	90%
	100%	-6.84%	-18.36%		-22.58%	100%	-9.04%
50%	-0.72%	-4.46%	-5.87%	50%	-0.77%	-6.70%	-9.13%
37.50%	0.63%	-2.35%	-3.42%	37.50%	1.05%	-2.91%	-4.46%
25%	1.92%	-0.05%	-0.69%	25%	2.94%	0.25%	-0.79%

Figure 3 Change in overweight and obesity prevalence under different circumstances.

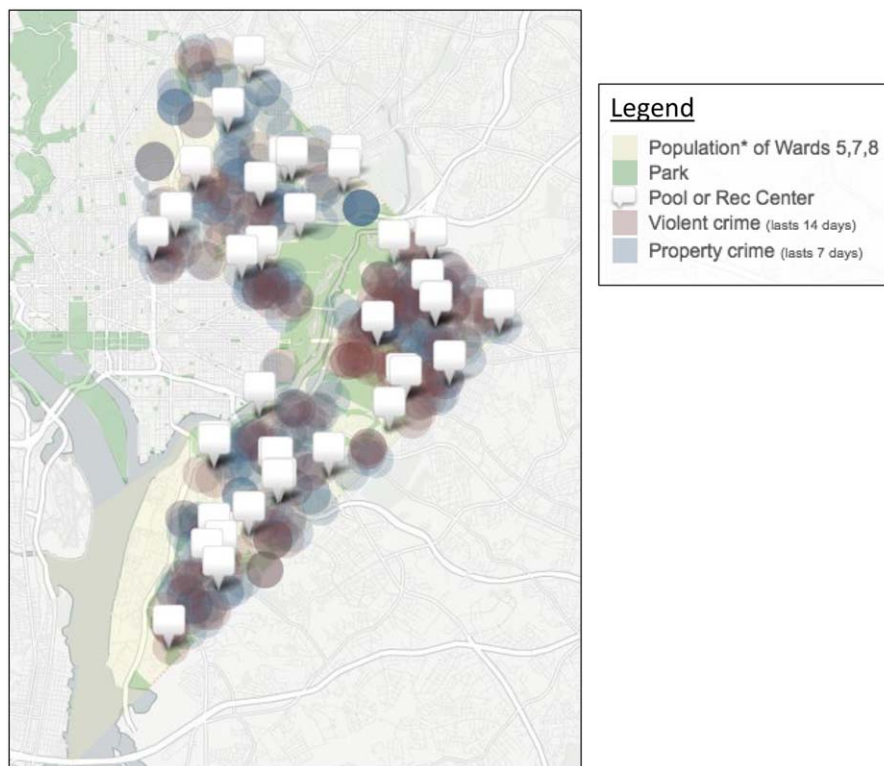


Figure 4 Map of crime and physical activity locations in Wards 5, 7, and 8 in Washington, DC.

obesity. When 50% of LTPA locations became accessible because of reduced crime impact, 31.91% (95% CI: 31.89-31.92) of women exercised per day, yielding a 2.91% (95% CI: 2.88-2.94) annual reduction in the proportion of women with obesity. Finally, when crime reductions led to 90% LTPA location accessibility, 36.35% (95% CI: 36.34-36.37) of women exercised per day, yielding an annual 4.46% (95% CI: 4.35-4.58) reduction in the proportion with obesity.

At 50% baseline exercise probability, when 10% of LTPA locations were accessible, on average, 26.17% (95% CI: 26.15-26.18) of women exercised per day, yielding a 0.77% (95% CI: 0.74-0.79) annual reduction in the proportion of women with obesity. When crime reductions led to 50% LTPA location accessibility, 42.53% (95% CI: 42.52-42.54) of women exercised per day, yielding a 6.70% (95% CI: 6.61-6.78) annual reduction in the proportion of women with obesity. Finally, when 90% of LTPA locations became accessible with crime reductions, 48.48% (95% CI: 48.46-48.50) of women exercised per day, yielding an annual 9.13% (95% CI: 9.05-9.21) reduction in the proportion with obesity.

Scenario 3: Isolated impact of crime reduction on LTPA and obesity prevalence

At 100% baseline probability to exercise, with 10% LTPA location accessibility, on average, 52.31% (95% CI: 52.30-52.32) of women exercised per day, yielding an annual 9.04% (95% CI: 9.02-9.06) reduction in the proportion of women with obesity. Subsequently,

at 50% LTPA location accessibility, 85.04% (95% CI: 85.03-85.05) of women exercised per day, yielding a 20.11% (95% CI: 20.07-20.14) reduction in the proportion of women with obesity. Finally, at 90% LTPA location accessibility, 96.93% (95% CI: 96.91-96.95) of women exercised per day, yielding a 24.38% (95% CI: 24.33-24.43) reduction in the proportion of women with obesity over a year.

Effect of crime parameters on LTPA

Our model predicted that LTPA location availability was most sensitive to changes to the radius of crime impact, while changes to crime’s duration and effect produced only small changes to LTPA location availability. Figure 4 (<https://aphez.github.io/vpop-dc-crime-map-2014/>) is a representative map of crime and LTPA locations when the radius is 0.33 miles, the durations for violent crime and property crime are 14 and 7 days, respectively, and the effect of each crime is a 20% reduction in going to a specified LTPA location. The link provides an interactive map on which radius, duration, and effect of crime can be changed to visualize relationships between different combinations of crime and LTPA location accessibility.

Discussion

Our study aimed to examine the relationship between crime, LTPA, and obesity in a population of African American women in a resource-limited urban setting. While crime can affect obesity through

various mechanisms, our study focused specifically on how crime's spatial nature can impact people's ability and willingness to access LTPA locations in an affected area, either on the travel route to or at LTPA locations. We found that when baseline exercise probability—which includes other individual, social, and environmental characteristics that might influence one's decision to exercise (e.g., family and employment commitments)—is low, reducing crime's impact has the least influence on LTPA participation and obesity reduction. As baseline exercise probability increases, the impact of crime becomes more relevant, as reductions in crime and subsequent increases in LTPA location accessibility have a larger impact on LTPA participation. Our model demonstrates that the relationship between crime and LTPA is nonlinear and depends on the baseline exercise probability. Crime has a small effect on LTPA when the baseline exercise probability is small, but crime becomes an increasingly important determinant of LTPA as the baseline exercise probability increases.

Our models may help to explain the mixed and null findings in prior epidemiologic studies related to crime's impact on exercise (8-10). The heterogeneity of findings in prior research may exist because these studies were conducted in populations with different underlying baseline probabilities to exercise. For example, null results in previous studies may be due to the fact that these studies were conducted in populations with a low baseline probability to exercise.

Additionally, our study suggests the need for policies that simultaneously address crime and individual- or environmental-level factors limiting baseline probability to exercise. Based on our findings, the most effective policies to improve LTPA in resource-limited communities might include efforts that reduce crime indirectly as part of a broader community improvement strategy and have potential to improve the baseline likelihood of exercise among women living in communities with limited resources for PA. These may include economic development initiatives, urban renewal, and neighborhood development efforts and policies to provide subsidized child care and health care (29,30). While we were unable to explicitly examine other factors that influence the baseline exercise probability in this study, it is likely that a low baseline exercise probability arises from barriers, such as time and financial resource constraints, that supersede crime's influence on LTPA. To increase LTPA participation in resource-limited communities where the baseline exercise probability is low, it will be important to better understand these other barriers to LTPA. Future studies might explore the full range of potential barriers—environmental, social, and individual—to identify those that are the biggest impediment to baseline probability to conduct LTPA among residents of resource-limited communities.

Understanding how crime may impede LTPA in urban areas is important, given that while nationally, crime is decreasing overall, there has been an uptick in crime in urban areas similar to Washington, DC (31). Our model is specific to Washington, DC, but exploring scenarios that vary the baseline exercise probability can provide insights into the impact of crime reduction policies in other cities with different baseline probabilities to exercise. Our findings might be applicable to other cities such as Chicago, Milwaukee, Detroit, and Baltimore. We also consider a scenario wherein the baseline probability to exercise is 100%. While we acknowledge this is a highly unlikely scenario, this allows us to isolate the effect of crime reduction on LTPA, overweight, and obesity. This scenario suggests that if no other factors affect LTPA except for crime, a near complete reduction in the impact of crime would decrease obesity prevalence by close to one-quarter. Importantly, we see that if future

policy efforts can address barriers to LTPA to increase the baseline exercise probability, it would become important to more directly consider the effect of crime on LTPA.

An important and unique contribution of our modeling approach is our ability to examine the geospecific nature of the relationship between crime and LTPA. Our findings suggest that an important policy lever may include efforts to alter people's perceptions of the proximity of a crime given that the sensitivity analysis demonstrates changing the radius of crime's impact is the most important mechanism through which crime affects LTPA. Radius as a crime parameter may represent how proximal people feel to crime (i.e., agents may alter their behavior due to a crime that occurred 0.25 miles away from a LTPA location if they feel that this is close to them, but may not be affected by a crime that occurred 0.75 miles away if they do not feel that this is proximal). Policies and interventions that change people's perceptions of crime's proximity to them, such that they feel safer, can be done in parallel with crime reduction efforts. This might include community engagement efforts, community policing to build relationships and trust between communities and police departments (32,33), increased police presence around frequently used LTPA locations such as parks and community recreational centers, and public-private partnerships for the development of safe, low-cost, commercial gyms—especially in locales, such as Washington, DC's Ward 8, where no commercial gyms currently exist (34,35). Unlike traditional epidemiologic studies that rely upon counts or density measures of crime, the agent-based model allowed us to differentiate between accessibility to LTPA locations, which accounts for the geospatial nature of crime, from commonly used aggregate measures of crime. For example, a community may experience large numbers of crime, but this may not necessarily deter LTPA if crimes occur far from LTPA locations, while even a small amount of crime near parks or recreational centers may impact accessibility and deter LTPA.

This study also had limitations. All models are a simplification of reality and cannot account for all possible factors that may affect PA decision-making. Our model included a number of simplifying assumptions, such as crime having the same effect on LTPA behavior regardless of the time of day or type of crime within each category (property or violent crime), and a constant effect through the entire affected radius. We did not account for differences in the quality of LTPA locations. Our use of objective measures of crime may not accurately reflect agents' perceptions of crime. Recent studies have observed weak correlations between perceptions of crime and actual crime incidents (6,36) and have even suggested these constructs to be measuring different aspects of crime (36). However, both objective and subjective (6) measures of crime are deemed important correlates of leisure PA. We also did not examine the specific factors that contribute to the baseline probability to exercise. We also considered only one potential mechanism through which crime might influence obesity, but crime also affects obesity through changes to the food environment (37) or through psychological stress and physiological changes (38). When calculating body weight changes for each woman over the course of the year, we assumed that compensatory eating did not occur (i.e., women consumed the same number of calories despite doing more PA in response to increased PA location accessibility). Our model simulated behavior of and used data specific to an urban, low-income population of African American women. This may limit generalizability of our findings to other populations or to suburban or rural areas.

Conclusion

Given the pressing need to address the obesity epidemic, it is important to find ways to increase LTPA, particularly in populations at high risk for obesity and a sedentary lifestyle such as low-income African American women. In our study, we examined how reductions in crime, by changing the accessibility to LTPA locations, can affect LTPA participation and obesity prevalence. Our results suggest that the influence of crime on LTPA likely becomes more important as other psychosocial and socioeconomic factors that influence propensity to exercise are addressed. Thus, policies that aim to reduce obesity by increasing LTPA should take a multilevel approach that targets individual-level and environmental barriers, including crime. In particular, efforts that target crime through urban renewal efforts and policies to improve perceived safety in resource-limited urban communities may be particularly effective in improving physical activity levels and cardiometabolic health for high-risk populations. **O**

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