Practice of Epidemiology

Limiting Alcohol Outlet Density to Prevent Alcohol Use and Violence: Estimating Policy Interventions Through Agent-Based Modeling

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Increasing alcohol outlet density is well-documented to be associated with increased alcohol use and problems, leading to the policy recommendation that limiting outlet density will decrease alcohol problems. Yet few studies of decreasing problematic outlets and outlet density have been conducted. We estimated the association between closing alcohol outlets and alcohol use and alcohol-related violence, using an agent-based model of the adult population in New York City. The model was calibrated according to the empirical distribution of the parameters across the city's population, including the density of on- and off-premise alcohol outlets. Interventions capped the alcohol outlet distribution at the 90th to the 50th percentiles of the New York City density, and closed 5% to 25% of outlets with the highest levels of violence. Capping density led to a lower population of light drinkers (42.2% at baseline vs. 38.1% at the 50th percentile), while heavy drinking increased slightly (12.0% at baseline vs. 12.5% at the 50th percentile). Alcohol-related homicides and nonfatal violence remained unchanged. Closing the most violent outlets was not associated with changes in alcohol use or related problems. Results suggest that focusing solely on closing alcohol outlets might not be an effective strategy to reduce alcohol-related problems.

alcohol; alcohol outlets; public health; simulation; violence

Abbreviations: ABM, agent-based model; NYC, New York City.

Alcohol use is one of the leading causes of death and years of potential life lost worldwide (1). In the United States, it is estimated that alcohol use was responsible for approximately 88,000 deaths and 2.5 million years of potential life lost annually during the period of 2006–2010 (2). As a result of the overwhelming evidence showing the causal connection between alcohol misuse and health and social problems at the population level (e.g., violent victimization), reducing alcohol misuse is considered a public health priority (3, 4).

Alcohol availability has been directly associated with alcohol misuse and alcohol-related problems (5). Although there is some controversy regarding the robustness of the current evidence (6, 7), expert recommendations suggest limiting alcohol availability through reducing outlet density as one of the key policies to reduce alcohol-related harm (8, 9). Alcohol outlets are hypothesized to increase alcohol-related problems due to: 1) the concentration of people around alcohol establishments; 2) the attraction of high-risk people to common places; and 3) the

concentration of alcohol establishments in neighborhoods with social norms that lead to more harmful drinking behaviors (10). Further theoretical and empirical developments were proposed by Gruenewald's niche theory and assortative drinking model, in which high density of alcohol outlets will lead to a differentiation of establishments to capture segments of the clientele (e.g., sports bar). This will lead to stratification of clients into "types" of drinkers, including problematic drinkers, adding to the concentration of alcohol-related problems (10, 11).

While the association between alcohol outlet density and alcohol use and problems has been extensively studied, there is limited evidence on the association between changing alcohol outlet policies and alcohol-related harm within a particular geographic location (5). An example of a policy change is the gradual privatization of alcohol retail sales in British Columbia, which resulted in increased alcohol outlet density; these changes have been associated with a higher risk of alcohol misuse and alcohol-related problems and deaths

(12–15). Reductions of alcohol outlet density, on the other hand, resulted from the implementation of legal changes to the alcohol policy of New Orleans, Louisiana, in 1997 (e.g., higher license fees, bans on selling alcohol through windows). In this case, the implementation of these policies was premise-specific, attenuating the association only between off-premise alcohol outlet density and violent crimes (16). Still, evidence on the impact of closing outlets, independent of co-occurring alcohol policies and social factors, is very limited.

In the absence of empirical data, simulation studies can provide important insights into the mechanisms and potential impact of policy changes. Agent-based models (ABMs) are a type of computational model that can simulate complex systems by incorporating multiple sources and levels of information (17). In an ABM, agents have properties (e.g., sex, age, level of drinking, living in a certain neighborhood), they perform actions (e.g., moving around, drinking alcohol), and they follow rules (e.g., interaction within a social network, selection of alcohol outlets) within a spatial and temporal environment (e.g., a city, across 20 years) (18). In a well-calibrated ABM (i.e., when the computational model adequately reproduces key aspects of the social phenomenon under investigation), simulated experiments within the model can reveal important information about a public health problem. Indeed, ABMs have been used as tools to evaluate the impact of policies such as targeted versus universal changes in collective efficacy to reduce population levels of violent victimization as well as isolated and combined strategies to reduce HIV transmission (19, 20). Efforts to simulate alcohol use within complex systems have also been conducted (21, 22).

In the present study, we used an ABM in order to estimate the association between closing alcohol outlets at various levels in a simulated New York City (NYC) and population levels of drinking and violence. We designed 2 types of intervention: one focusing on closing establishments in areas with a high density of alcohol outlets and the other on closing outlets with high levels of surrounding violence. Following current recommendations, we hypothesized that a reduction in alcohol outlet density and closing problematic outlets would lead to a lower prevalence of alcohol misuse and alcohol-related violent victimization and homicides.

METHODS

We created an agent-based computational model simulating NYC by updating prior well-calibrated models (19, 23). The ABM allowed us to model dynamic relationships between agents and their environments, enabling us to approximate the processes that contribute to drinking and violence in the city. The model was parameterized and calibrated using data from NYC when possible (see Web Appendix 1, available at <https://academic.oup.com/aje>, for a description of model calibration). Key features of the model are summarized below. For more detail, we have provided the pseudocode in Web Appendix 2.

Model initialization

Agents and neighborhoods. The physical area of NYC was modeled as a 400-x-625-cell grid, which was divided into

59 units representing community districts. These units were scaled to approximate the size and location of the neighborhoods in NYC. Our model was populated with 256,500 agents in order to simulate a 5% sample of the adult population of NYC in the year 2000, and agents were placed within neighborhoods such that the distribution of age, sex, race, and income in the model approximated the distribution in the corresponding NYC neighborhood in 2000 (24). Some neighborhood characteristics, such as the proportion unemployed, living in female-headed households, and foreign born, were assigned to each neighborhood according to US Census data from 2000. Other neighborhood characteristics were calculated from the model at each time step, including racial composition, average income, violence, and drinking.

Agents were connected to each other in a social network. Network members were probabilistically assigned based on salient demographic features (e.g., age, sex, race) and behavioral similarities (e.g., drinking status and geographic proximity) (25, 26). In order to create a social network, agents were assigned a target number of network members, averaging 3 members per agent (25). For simplicity, the social networks were created at baseline and did not change over the model run.

A total of 790 police officers were included in the model, representing 5% of the average number of officers in NYC between 1990 and 1993 (27). Police officers were randomly placed within neighborhoods so that the number of officers per neighborhood was proportional to the average number of officers in the corresponding NYC neighborhood during 1990–1993, before the police force was increased as part of an order-maintenance policing strategy.

Alcohol outlets and baseline drinking status. On-premise alcohol outlets (e.g., bars and restaurants) and off-premise alcohol outlets (e.g., liquor stores) were randomly placed to approximate the density in each NYC neighborhood. Outlet density was determined by the number of active liquor licenses in each neighborhood in 2002, which we gathered from the New York State Division of Alcoholic Beverage Control (28).

Agents' baseline drinking statuses were then determined probabilistically, based on individual sociodemographic and neighborhood-level characteristics. Sociodemographic characteristics included gender, age, race, education, and income. Neighborhood characteristics included income, racial composition, average amount of violence, percentage of light and heavy drinkers, and density of on- and off-premise alcohol outlets. To model these probabilities, we used individual-level data from the World Trade Center Study, a longitudinal study of adults living in the NYC metropolitan area initiated in 2002 after the September 11th terrorist attacks (29), and neighborhood-level data from the New York Social Environment Study conducted in 2005 (30, 31). Heavy drinking was defined as consuming more than 60 alcoholic drinks per month for men and more than 30 alcoholic drinks per month for women, following the definition of the Behavioral Risk Factor Surveillance System, consistent with the excessive drinking definition of the dietary guidelines for Americans, 2015–2020 (32, 33); light/moderate drinking was any monthly drinking that did not meet the heavy drinking threshold.

Light/moderate drinkers were additionally assigned a preference for drinking in public or at home, with probabilities

calculated from the National Epidemiologic Survey of Alcohol and Related Conditions, a national study of US households (34). After taking into account preference for drinking in public or private, a random outlet within the designated radius was assigned to the agent at baseline. Heavy drinkers were randomly assigned an on-premise and an off-premise outlet within the designated radii. A detailed description of outlet selection is presented in Web Appendix 1.

Agent behaviors and experiences

Aging, mortality, and movement. At each time step, agents aged 1 year and died according to probabilities derived from the 2000 NYC adult all-cause mortality rates (35). Additionally, agents could move from one neighborhood to another. An agent's probability of moving was based on income, duration of residence in the current neighborhood, and recent violent victimization; it was calibrated using data from the Detroit Neighborhood Health Study (36) and the Panel Study of Income Dynamics (37).

The composition of alcohol outlets, drinking and victimization status of friends, and neighborhood characteristics were updated at each time step. Consistent with research finding important influences of neighborhood conditions on alcohol consumption and violence (31, 38), neighborhood characteristics contributed 10% and social network characteristics contributed 15% of the agents' probabilities of drinking and violence.

Alcohol consumption and preferred alcohol outlet. At each time step, agents had the opportunity to change their drinking status (e.g., from heavy to light/moderate drinking). Drinking status transitions were based on the agent's drinking status and victimization at the previous time step, sociodemographic characteristics, neighborhood characteristics, and also on the drinking status of the agent's network ties and of other individuals at the agent's preferred alcohol outlet (39).

Agents also had the option of selecting a new preferred outlet, taking the outlet identity into consideration when making a selection. On-premise outlet identities followed Fitzpatrick and Martinez's (40) formalization of Gruenewald's ecological niche theory (10), in which on-premise outlets specialize based on sociodemographic and drinking characteristics of patrons. Off-premise outlet identities were based on select sociodemographic characteristics of patrons. For agents searching for an improved outlet selection, if the new outlet's identity was more similar to the agent's identity than the agent's current preferred outlet, the agent's preferred outlet would be updated to the new outlet. Similarity between the agent's identity and the outlet's identity was measured with the Euclidean distance, which was calculated by taking the square root of the sum of squared differences for each feature included in the outlet identity (on-premise outlets included race, income, education, age, and drinking status; off-premise outlets included income, education, and race; all variables were standardized to the same scale). The number of an agent's friends at an outlet was also incorporated into the Euclidean distance for on-premise outlets, such that the distance decreased as the number of friends at an outlet increased.

Violence perpetration and victimization. The violence model was formalized following the ABM from Cerdá et al. (23) on public health and criminal justice approaches to prevent urban

violence. In short, at each time step, agents could be victims or perpetrators of violence, either fatal or nonfatal. Probabilities of violent perpetration were calculated from the National Epidemiologic Survey of Alcohol and Related Conditions, and violent victimization probabilities were calculated from the World Trade Center Study. Data from the Office of the Chief Medical Examiner in NYC were used to determine homicide probabilities (41). To identify potential perpetrators and victims of violence, probabilities of perpetrating violence and of being a victim of violence were determined based on agents' individual and neighborhood-level sociodemographic characteristics, their drinking statuses and histories of violence, the history of violence around their preferred alcohol outlets, and their friends' recent victimization or perpetration of violence. Potential perpetrators searched for potential victims within a 15-cell radius around their location, and any agent that had not already been victimized at that time step became a victim unless a police officer was present within a 2-cell radius of the potential victim. Violent incidents in which either the victim or perpetrator was a heavy drinker were identified as alcohol-related.

Intervention scenarios

A baseline model, with no intervention, was considered, along with 5 alcohol outlet-density intervention models, which capped the alcohol outlet density at the 90th, 80th, 70th, 60th, and 50th percentile of the empirical alcohol outlet density in NYC. We also evaluated 5 targeted violence-intervention models in which the most violent 5%, 10%, 15%, 20%, and 25% of outlets were closed.

The density of on- and off-premise alcohol outlets was set at baseline, and the deciles used in the intervention scenarios were determined from the baseline distribution. In the 90th percentile intervention, each neighborhood was first determined to be over or under the 90th percentile for on-premise outlets. If a neighborhood was over the threshold, the proportion of outlets that needed to be closed in order to meet the threshold was calculated. The designated number of outlets was then closed. This was repeated for off-premise outlets in each neighborhood. The alcohol outlet densities in each neighborhood were then recalculated, based on the number of remaining outlets. Agents with closed outlets were able to look for a new preferred outlet within the specified radius. Each of the other 4 interventions were identical to this process, except that the percentile setting the threshold for alcohol outlet density was decreased.

In the targeted violence intervention, all outlets in the model were first ordered according to the number of violent events that occurred within a 3-cell radius around the outlet at the last time step. Next, the number of outlets needed to close to approximate the specified percentage closed (5%–25%, depending on the intervention) was calculated. Finally, using the violence-ordered list, the target number of outlets was closed. Agents with closed outlets were able to look for a new preferred outlet within the specified radius.

To test the robustness of our assumptions about neighborhood and social network influences, among other parameters (see Web Table 1), on agent behavior, we performed a range of sensitivity analyses, described in detail in Web Appendix 1.

The ABM was created with Recursive Porous Agent Simulation Toolkit for Java (RepastJ), version 3.0 (Argonne

National Laboratory, Lemont, Illinois), and implemented in Eclipse, version 4.2 (Eclipse Foundation, Ottawa, Ontario, Canada). To account for random variation across model runs, each model scenario was repeated 50 times, and the median, 2.5th, and 97.5th, percentiles were reported from the pooled results.

RESULTS

We were able to calibrate the model such that the agents' demographic factors and behaviors relating to drinking and violence reflected those of the adult population of NYC in 2000 (Table 1). Alcohol outlet density and distribution was also well-balanced in reference to the empirical distribution of outlets in NYC.

Table 2 shows the characteristics of the alcohol outlets under the no-intervention scenario, each of the 5 alcohol outlet-density intervention scenarios, and each of the 5 targeted violence-intervention scenarios. As more outlets were closed, the concentration of heavy drinkers at the remaining outlets increased: the percentage of on-premise outlets with 50% or more heavy drinkers went from 5.6% (95% CI: 4.9, 6.5) at baseline to 7.0% (95% CI: 5.7, 9.4) when capping at the 50th percentile. At off-premise outlets this proportion went from 1.3% (95% CI: 1.0, 1.5) at baseline to 5.0% (95% CI: 4.5, 5.5) when capping at the 50th percentile. In contrast, closing the most violent outlets had very little impact on the concentration of heavy drinkers at the remaining outlets: when closing the top 25% most violent outlets, we observed less than 1 percentage point decreases in on- and off-premise outlets with more than 50% heavy drinkers compared with the aforementioned baseline values (on-premise, 25% violence intervention: 4.9%, 95% CI: 4.1, 6.1; off-premise, 25% violence intervention: 0.8%, 95% CI: 0.5, 1.0).

For baseline and each intervention, Table 3 shows the city-wide average proportion of agents who were nondrinkers, light drinkers, and heavy drinkers, as well as the average percent of alcohol-related non-fatal violence and rate of alcohol-related homicide. The percentage of nondrinkers at baseline was 45.8% (95% CI: 45.7, 45.9); this number increased in a dose-response manner by 0.4–3.6 percentage points over the different density intervention scenarios. The percentage of light drinkers decreased from 42.2% (95% CI: 42.1, 42.3) by 0.5–4.1 percentage points across the interventions. Heavy drinkers increased slightly as the intervention became more restrictive, from 12.0% (95% CI: 11.9, 12.1) at baseline to 12.5% (95% CI: 12.4, 12.5) at the 50th percentile intervention. The targeted violence interventions did not affect the population drinking proportions, and the violence-related outcomes did not deviate meaningfully from baseline in any intervention scenario.

Results from the sensitivity analyses showed that the proportions of light drinkers and nondrinkers in the density intervention were sensitive to changes to the neighborhood influence but robust to changes in all other model specifications (Web Figure 1). The targeted violence intervention was robust to changes in all examined model specifications (Web Figure 2).

DISCUSSION

In a well-calibrated simulation of NYC, interventions focused on decreasing alcohol outlet density in high-density neighborhoods

led to a lower prevalence of light drinkers and to a higher prevalence of nondrinkers, in a dose-response fashion across levels of intervention. Contrary to expectations, the prevalence of heavy drinking at the population level increased modestly. No change was observed for alcohol-related violent victimization or homicides. Targeted interventions aiming to close problematic outlets (those concentrating violence) produced no change in alcohol use prevalence or in violent victimization and alcohol-related homicides. In general, agents that used alcohol were successful in finding other outlets, generating under some intervention scenarios the unintended consequence of concentrating drinkers, especially heavy drinkers, in a single place, leading to a small but consistent increase in heavy drinking and alcohol-related problems.

These findings challenge the current recommendations of decreasing alcohol outlet density or targeting problematic outlets as effective strategies to reduce alcohol misuse and alcohol-related problems (5, 8). Evidence underlying current recommendations come mostly from ecological studies showing that areas with a higher concentration of alcohol outlets have higher rates of alcohol misuse and alcohol-related problems (42). Longitudinal studies and natural experiments have also examined how changes in outlet density are associated with changes in alcohol problems (5, 43). The majority of the alcohol outlet density research, however, has studied the changes associated with increasing alcohol outlet density. Few studies have systematically looked at changes associated with reducing outlet density, all of them as results of unintentional causes (e.g., civil unrest following the verdicts acquitting the police officers accused of beating Rodney King) or broader multicomponent alcohol policies (16, 44, 45), rather than targeted policies to reduce alcohol outlet density.

As we saw in this study, groups prone to change their drinking status are those who are less likely to develop a regular and harmful drinking behavior (light drinkers); thus they are susceptible to modifying their drinking choices if their drinking environment changes (i.e., closure of their preferred outlet). Making it harder to buy alcohol for light drinkers can lead them to decrease or cease drinking. On the other hand, heavy drinkers and agents involved in violence around specific outlets were able to adapt their behavior to the new environmental context by selecting a new outlet, indicating that these interventions will likely lead to small or no changes among this group, and they could even produce the unintended consequence of concentrating heavy drinkers and increasing alcohol-related problems. That concentrating drinkers at a single place or time can lead to an increase of alcohol-related problems is actually the basic mechanism on which much of the alcohol-outlet research focuses (11, 46).

The interventions we proposed, while focused on only 2 aspects of alcohol outlet policies, were aimed to simulate somewhat realistic regulations. To close a fixed number or proportion of outlets across neighborhoods is not only unrealistic, but also makes little sense for neighborhoods with a low density of outlets and alcohol-related problems (47). To the contrary, closing outlets in neighborhoods with an "excess" of alcohol outlets, or closing problematic outlets, seems to be a reasonable public health approach, consistent with current recommendations (8). The same reasoning (closing public places), although in a different context, was used to simulate interventions to decrease

Table 1. Selected Population and Built Environment Calibration Estimates of the Agent-Based Model and Comparisons With Empirically Available Data, New York City, 2000–2006

Baseline Characteristic	ABM		NYC Estimate ^a	Estimate From Other Data Sources ^b
	Estimate	95% CI		
Demographic factors, %				
Male sex	46.4	46.4, 46.4	47.4	N/A
Age group, years				
18–24	13.8	13.8, 13.9	12.4	N/A
25–34	20.3	20.2, 20.4	19.3	N/A
35–44	19.7	19.7, 19.8	21.5	N/A
45–54	17.7	17.6, 17.7	17.9	N/A
55–64	15.6	15.5, 15.7	11.8	N/A
≥65	12.9	12.8, 12.9	17.0	N/A
Race/ethnicity				
White	38.2	38.2, 38.2	35.0	N/A
Black	23.0	23.0, 23.0	24.5	N/A
Hispanic	25.1	25.1, 25.1	27.0	N/A
Other race/ethnicity	13.8	13.8, 13.8	13.5	N/A
Baseline drinking status, %				
Nondrinker	45.8	45.7, 45.9	55.2	45.6
Light/moderate drinker	42.2	42.1, 42.3	47.0	41.4
Heavy drinker	12.0	11.9, 12.1	11.6	13.0
Drinking transitions, %				
Non → light/moderate	16.8	16.8, 16.9	20.8	15.7
Light/moderate → non	18.5	18.4, 18.5	15.0	22.9
Light/moderate → heavy	9.3	9.2, 9.3	11.8	24.5
Heavy → light/moderate	33.8	33.7, 34.0	35.5	55.4
Violent victimization, %				
Past-year victimization	4.3	4.3, 4.3	3.6	1.4–8.0
Lifetime victimization	41.6	41.5, 41.7	32.3	15.0–50.8
Violent perpetration, %				
Past-year perpetration	0.64	0.64, 0.65	N/A	0.45–3.2
Lifetime perpetration	13.1	12.9, 13.2	N/A	10.5–17.7
Homicide rate, per 100,000				
Total homicide	12.3	11.8, 13.3	10.7	N/A
Alcohol-related homicide	3.2	2.8, 3.7	3.1	N/A
Neighborhood alcohol outlet density per square mile ^c				
On-premise	22.8 (12.9–51.4)		21.8 (14.1–50.1)	N/A
Off-premise	52.3 (31.9–87.2)		52.8 (31.6–91.1)	N/A

Abbreviations: ABM, agent-based model; CI, confidence interval; N/A, not available; NYC, New York City.

^a World Trade Center Study (29); New York Social Environment Study (30, 31); US Census, 2000 (24); NYC Office of Chief Medical Examiner (35); New York State Division of Alcoholic Beverage Control (28).^b National Epidemiologic Survey of Alcohol and Related Conditions (34).^c Values are expressed as median (interquartile range).

contagion for an influenza-like epidemic; results for that intervention were also unexpectedly null (48).

Our study has several strengths. We were able to build an ABM using reliable administrative and survey data, as well as information from multiple sources and studies conducted,

in most cases, in NYC. The calibration process showed that the final model closely resembled NYC in its sociodemographic characteristics, alcohol use, and violence indicators. Moreover, our results were robust to multiple specifications and assumptions, including changing the relative influence of

Table 2. Outlet Characteristics Under Simulated Interventions Targeted on the Alcohol Outlet Density and Density of Outlets with High Levels of Surrounding Violence, in a Simulation of New York City

Outcome	Intervention in Neighborhoods at the Top of the Alcohol Outlet-Density Distribution											
	No Intervention		Capping at 90th Percentile		Capping at 80th Percentile		Capping at 70th Percentile		Capping at 60th Percentile		Capping at 50th Percentile	
	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI
Total alcohol outlets with $\geq 25\%$ heavy drinkers	83.4	82.9, 84.1	84.6	83.6, 85.3	86.4	85.7, 87.0	87.9	87.0, 88.7	89.4	88.6, 90.3	90.8	89.9, 91.9
Total alcohol outlets with $\geq 50\%$ heavy drinkers	3.3	3.0, 3.8	3.4	2.9, 3.9	3.5	3.0, 4.1	4.2	3.9, 5.0	5.2	4.5, 6.0	5.7	5.1, 6.6
On-premise outlets with $\geq 25\%$ heavy drinkers	86.2	85.0, 87.4	88.1	86.6, 89.1	91.5	89.6, 92.5	91.3	90.1, 93.1	91.8	90.1, 93.1	92.2	90.3, 94.0
On-premise outlets with $\geq 50\%$ heavy drinkers	5.6	4.9, 6.5	5.8	4.7, 6.7	5.7	4.8, 7.3	6.6	5.5, 8.6	7.3	5.7, 8.8	7.0	5.7, 9.4
Off-premise outlets with $\geq 25\%$ heavy drinkers	80.9	80.0, 81.9	81.9	80.8, 82.6	83.5	82.7, 84.3	85.9	84.7, 86.6	88.1	87.3, 89.3	90.2	89.4, 91.2
Off-premise outlets with $\geq 50\%$ heavy drinkers	1.3	1.0, 1.5	1.4	1.2, 1.8	2.2	1.9, 2.6	2.9	2.6, 3.2	4.1	3.5, 4.7	5.0	4.5, 5.5
	Targeted Interventions on the Outlets With the Highest Surrounding Violence											
	No Intervention		Closing Top 5% Violent Outlets		Closing Top 10% Violent Outlets		Closing Top 15% Violent Outlets		Closing Top 20% Violent Outlets		Closing Top 25% Violent Outlets	
	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI
Total alcohol outlets with $\geq 25\%$ heavy drinkers	83.4	82.9, 84.1	83.9	83.1, 84.8	84.3	83.5, 85.1	84.9	83.9, 85.5	85.4	84.2, 86.4	85.9	85.0, 86.8
Total alcohol outlets with $\geq 50\%$ heavy drinkers	3.3	3.0, 3.8	3.2	2.7, 3.7	3.1	2.7, 3.7	3.1	2.8, 3.5	3.0	2.6, 3.7	2.8	2.4, 3.4
On-premise outlets with $\geq 25\%$ heavy drinkers	86.2	85.0, 87.4	86.0	84.8, 87.5	86.1	84.7, 87.6	85.9	84.7, 87.0	86	84.7, 87.4	87.2	86.1, 88.8
On-premise outlets with $\geq 50\%$ heavy drinkers	5.6	4.9, 6.5	5.3	4.3, 6.4	5.2	4.44, 6.5	5.3	4.5, 6.2	5.1	4.5, 6.2	4.9	4.1, 6.1
Off-premise outlets with $\geq 25\%$ heavy drinkers	80.9	80.0, 81.9	81.9	81.0, 82.8	82.5	81.5, 83.6	83.9	82.9, 84.6	84.5	83.2, 85.4	84.7	83.7, 85.5
Off-premise outlets with $\geq 50\%$ heavy drinkers	1.3	1.0, 1.5	1.1	0.9, 1.3	1.0	0.7, 1.3	0.7	0.5, 1.0	0.8	0.5, 1.0	0.8	0.5, 1.0

Abbreviation: CrI, credible interval.

Table 3. Prevalence of Alcohol Use and Violent Victimization Under Simulated Interventions Targeted on the Alcohol Outlet Density and Density of Outlets with High Levels of Surrounding Violence, in a Simulation of New York City

Outcome	Intervention in Neighborhoods at the Top of the Alcohol Outlet-Density Distribution											
	No Intervention		Capping at 90th Percentile		Capping at 80th Percentile		Capping at 70th Percentile		Capping at 60th Percentile		Capping at 50th Percentile	
	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI
Abstinent	45.8	45.7, 45.9	46.3	46.1, 46.3	47.3	47.2, 47.4	48.0	47.9, 48.1	48.7	48.7, 48.8	49.4	49.3, 49.5
Light drinkers	42.2	42.1, 42.3	41.7	41.6, 41.8	40.5	40.5, 40.6	39.8	39.7, 39.8	38.9	38.8, 38.9	38.1	38.0, 38.2
Heavy drinkers	12.0	11.9, 12.1	12.1	12.0, 12.1	12.2	12.1, 12.2	12.3	12.2, 12.4	12.4	12.3, 12.4	12.5	12.4, 12.5
Alcohol-related violence	1.2	1.2, 1.3	1.2	1.2, 1.3	1.2	1.2, 1.23	1.2	1.2, 1.3	1.2	1.2, 1.3	1.2	1.2, 1.3
Alcohol-related homicide ^a	3.3	2.8, 3.7	3.2	2.8, 3.7	3.3	2.89, 3.8	3.2	2.8, 3.8	3.3	2.8, 4.0	3.3	2.9, 3.7
Outcome	Targeted Interventions on the Outlets With the Highest Surrounding Violence											
	No Intervention		Closing Top 5% Violent Outlets		Closing Top 10% Violent Outlets		Closing Top 15% Violent Outlets		Closing Top 20% Violent Outlets		Closing Top 25% Violent Outlets	
	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI	%	95% CrI
Abstinent	45.8	45.7, 45.9	45.8	45.7, 45.9	45.8	45.7, 45.9	45.8	45.7, 45.9	45.8	45.7, 45.9	45.8	45.7, 45.8
Light drinkers	42.2	42.1, 42.3	42.2	42.1, 42.2	42.2	42.1, 42.3	42.2	42.1, 42.3	42.2	42.1, 42.3	42.2	42.1, 42.3
Heavy drinkers	12.0	11.9, 12.1	12.0	12.0, 12.1	12.0	12.0, 12.1	12.0	12.0, 12.1	12.0	12.0, 12.1	12.0	12.0, 12.1
Alcohol-related violence	1.2	1.2, 1.3	1.2	1.1, 1.3	1.2	1.2, 1.3	1.2	1.2, 1.3	1.2	1.2, 1.3	1.2	1.2, 1.3
Alcohol-related homicide ^a	3.3	2.8, 3.7	3.3	2.7, 3.7	3.2	2.8, 3.6	3.3	2.9, 3.7	3.2	2.8, 3.8	3.3	2.9, 3.7

Abbreviation: CrI, credible interval.

^a Values expressed as cases per 100,000 and 95% credible interval.

social network on individual behavior, the rules governing violence, and the influence of agents who share a preferred outlet on one another's drinking statuses.

Results should be also seen in light of the following limitations. First, although ABMs are a useful tool to add complexity and flexibility to the modeling process, they will always be a simplification of the real world, especially for problems in which psychological, social, and environmental components of individual and social behavior (such as alcohol use and violence) are interacting. This might be present in our ABM if, for example, we missed some possible mechanisms through which alcohol outlets might influence drinking and violence. Second, and in relation to the previous point, regulation of alcohol outlets can certainly be more complex than just reducing density or problematic outlets. For example, regulations can consider a minimum distance between outlet types or between outlets and sensitive locations such as schools, churches, or health facilities; densities could differ depending on the land use. We chose to focus only on outlet density and problematic outlets because most of the existing literature is specific to these issues, and we aimed to avoid generating overly complex models based on limited data on each of the potential interacting mechanisms. Third, even when using reliable data to build and calibrate the model, bias inherent to data collection (i.e., response bias) and uncertainty associated with parameter estimations can lead to error propagation across model runs. In addition, not all components in the model were based on NYC data (i.e., violence dynamics) or contemporary information (e.g., Census data from 2000, police officer allocation size from the early 1990s), leading to potential extrapolation bias or misrepresentation of current NYC dynamics. Finally, we did not differentiate between types of outlets (e.g., family restaurant vs. liquor bar) within the 2 broad categories considered (on- and off-premise). This decision stemmed from inconsistency across studies, for example, in how they defined outlet density (e.g., density per distance vs. per population), in what type of outlet they considered (e.g., bars, restaurant, off-premise) or for what outcome (e.g., drinking, violence), and in what setting (e.g., urban area in the United States) (7). There were also low count issues when representing specific types of outlets (e.g., bars) in our ABM (which represented only 5% of the real New York populations and alcohol outlet distribution), limiting the possibilities for programming other targeted interventions.

The results of our study suggest that closing alcohol outlets in high-density areas or with a history of violence as isolated policies might not be sufficient to reduce alcohol misuse and related problems. Furthermore, these policies might have the opposite result by concentrating heavy drinkers around and within alcohol outlets. Further studies should explore whether combining policies and prevention strategies might improve the health and social conditions of the population.

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