Alcohol Outlets and Binge Drinking in Urban Neighborhoods: The Implications of Nonlinearity for Intervention and Policy

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Objectives. Alcohol outlet density has long been associated with alcohol-related harms, and policymakers have endorsed alcohol outlet restriction to reduce these harms. However, potential nonlinearity in the relation between outlet density and alcohol consumption has not been rigorously examined.

Methods. We used data from the New York Social Environment Study (n = 4000) to examine the shape of the relation between neighborhood alcohol outlet density and binge drinking by using a generalized additive model with locally weighted scatterplot smoothing, and applied an imputation-based marginal modeling approach.

Results. We found a nonlinear relation between alcohol outlet density and binge drinking; the association was stronger at densities of more than 80 outlets per square mile. Binge drinking prevalence was estimated to be 13% at 130 outlets, 8% at 80 outlets, and 8% at 20 outlets per square mile.

Conclusions. This nonlinearity suggests that reductions in alcohol outlet density where density is highest and the association is strongest may have the largest public health impact per unit reduction. Future research should assess the impact of policies and interventions that aim to reduce alcohol outlet density, and consider nonlinearity in effects. (*Am J Public Health.* 2013;103:e81–e87. doi:10.2105/AJPH.2012.301203)

A substantial body of research has found that availability of alcohol, as measured by alcohol outlet density, is related to societal problems that include driving under the influence,[1,2] automobile crashes,[3–6] injuries,[7] suicide,[6] and violence.[8–22] Alcohol outlet density has also been related to higher mean alcohol consumption,[23–26] binge or heavy drinking,[27,28] alcohol disorders,[29] and liver problems.[30]

Recent systematic reviews have concluded that the literature supports restriction of alcohol outlet density as an effective measure to reduce alcohol-related harms.[31,32] Furthermore, a variety of policymaking bodies have endorsed alcohol outlet density restriction, specifically the Task Force on Community Preventive Services, the European Union, the World Health Organization, and Substance Abuse and Mental Health Services Administration.[31,33–36]

Although the literature strongly suggests that alcohol outlet density shapes alcohol-related outcomes, most of the existing research makes the implicit assumption that the relation is essentially linear. A recent review called for research that considers the shape of the relation between alcohol outlet density and alcohol-related outcomes because the shape has practical implications for intervention and policy.[31] If the relation were linear, interventions that aim to reduce alcohol outlet density at any baseline density would be equally effective. However, if the shape of the relation were nonlinear, interventions would have differing degrees of effectiveness in reducing alcohol-related harms depending on the baseline alcohol outlet density.

There is a limited body of work that has considered the shape of the relation between alcohol outlet density and various outcomes. Two studies on violence assessed potential nonlinear associations with alcohol outlet density, and found stronger relations with violence at higher outlet densities.[37,38] Only 1 study examined potential nonlinearity in the relation between alcohol outlet density and alcohol consumption; this study found substantially stronger relations between outlet density and harmful alcohol consumption for the highest category of outlet density. However, the use of a categorical approach (with an open-ended upper category) to examine density provides a limited assessment of the shape of the relation.[39]

There is a need for research that rigorously examines the shape of the relation between alcohol outlet density and alcohol consumption. Building on the extant research, we examined the relation between neighborhood alcohol outlet density and binge drinking in an urban population. We examined the shape of the relation by using a semiparametric general additive model with locally weighted scatterplot smoothing (loess) instead of assuming a standard form. Then we applied a marginal modeling approach to estimate prevalences of binge drinking associated with "setting" neighborhood alcohol outlet density to levels across the range of the data.[40,41]

METHODS

The New York Social Environment Study is a multilevel study designed to examine neighborhood level exposures, including economic, social, and structural characteristics, and mental health and substance use in New York City. We conducted the study between June and December of 2005. We used random-digit-dial methods to contact and interview 4000 New York City residents. We included only landline telephones because of rules prohibiting random digit dialing to cell phones at that time; only 5% of households were cell phone–only in 2005.[42a] We interviewed 1 adult aged 18 years or older by telephone in each household; the respondent was the person who either most recently or would next celebrate his or her birthday (randomly selected). Respondents had the choice of completing the interview in English or Spanish. The cooperation percentage was 54%. We offered respondents $10 in compensation for their participation.

Respondents provided information about their residential address or nearest cross-streets so that their locations could be geocoded and linked to their neighborhoods of residence.[42b] The neighborhood units for this analysis were the 59 community districts in New York City. Community districts are recognizable neighborhood areas, each headed by an administrative community board, and many characteristics of these neighborhoods have been associated with health indicators.[42–46]

Measures

We interviewed respondents with a structured questionnaire that included questions on demographic and socioeconomic characteristics that were potential confounders of the relation of interest including age, race, gender, marital status, place of birth, education, income, years lived in the current neighborhood, and interview language. We acquired neighborhood median household income data from the 2000 Census.[47]

We acquired alcohol license data from the New York State Division of Alcoholic Beverage Control/State Liquor Authority by using the online public license query. We calculated the number of off-premise active liquor licenses per neighborhood; these are licenses that permit only the retail sale of alcoholic beverages directly to consumers for their consumption (i.e., alcoholic beverages may not be sold for resale). Alcoholic beverages cannot be consumed on the premises of establishments holding these licenses, nor are any open containers of alcoholic beverages allowed on the premises. License type abbreviations included in this category are A, AX, C, DS, DX, E, L, ST, W, and AW (class 122). We calculated density of alcohol outlets as outlets per square mile.

We assessed drinking behavior by using the National Institute on Alcohol Abuse and Alcoholism–recommended questions on binge drinking,[48] and the World Mental Health Comprehensive International Diagnostic Interview alcohol module.[49,50] The outcome was binge drinking based on the National Institute on Alcohol Abuse and Alcoholism binge drinking questions that assessed the number of occasions in the past 12 months where 4 (for women) or 5 (for men) or more drinks were consumed within a 2-hour period. This is drinking behavior that will raise the blood alcohol content beyond 0.08% in most people, which is considered legally drunk.[48] Respondents who reported binge drinking monthly or more frequently were classified as binge drinkers in this analysis to focus on binge drinking that poses more substantial public health risk. We used the World Mental Health Comprehensive International Diagnostic Interview alcohol measures that include a retrospectively recalled history of alcohol use to capture the history of drinking before residence in the current neighborhood.

Analysis

We weighted all analyses by the ratio of the persons in the household to phone lines in the household to account for the probability of selection for interview. We included individual demographic and socioeconomic characteristics that were conceptually considered confounders (listed in measures) and neighborhood median income in all multivariable analyses. In cross-sectional neighborhood studies, there is a concern that associations represent both social selection (e.g., people who binge drink move to certain neighborhoods) and social causation (e.g., neighborhood characteristics affect binge drinking) processes and the 2 cannot be differentiated.[51] Therefore, in this analysis we adjusted for history of drinking as a confounder to account for 1 contributor to social selection; by controlling for drinking history we ensure that observed associations were not attributable to an effect of people with certain drinking histories being likely to move to certain types of neighborhoods. We applied multiple imputation and a missingness indicator approach to variables where some respondents declined to answer and compared results of analyses that applied these 2 approaches; differences in results between the approaches were negligible, so we used the missingness indicator approach in all analyses for simplicity.

We conducted several descriptive analyses initially. We used propensities for living in low- compared with high–alcohol outlet density neighborhoods, estimated as a function of confounders (listed in measures), to examine the potential that analyses would rely on extrapolation. We examined neighborhood alcohol outlet density and all covariates in association with binge drinking in bivariable analysis. For multivariable analyses, we used generalized additive models with loess (family binomial, logit-link) for alcohol outlet density.[52] We also modeled the confounder median income with loess to allow nonlinearity in the association with binge drinking. We used a smoothing bandwidth of 0.7 in the final analysis; bandwidths between 0.5 and 0.9 produced extremely similar estimates, and smaller bandwidths captured excessive random error.

These models are a generalization of generalized linear models that allow for combination of semiparametric (smooths) and parametric linear terms. The smooth terms can be fit with various smoothers; we used loess, a (local–linear) kernel regression smoother. Heuristically, the algorithm predicts the outcome at a point, $X=x$, with a local weighted regression of the points around $X=x$ (with the range of included points determined by the bandwidth) to find a local linear model where the weights of each point are based on their distance to x using a weight function called a kernel.

Based on these models, we applied a marginal modeling approach; we used this approach so that we could present model results as marginal relations on the additive scale.[40,41] This marginal modeling approach starts by using the generalized additive model to estimate the outcome for each individual in the population had he or she experienced set levels of alcohol outlet density of interest. Individual outcomes were then averaged across the population to assess prevalence of binge drinking with the set levels of alcohol outlet density. Applying this approach, we estimated prevalence of binge drinking if all residents had lived in neighborhoods with alcohol outlet density set to levels across the range of the alcohol outlet density in the data. In notation this is

$$(1)\quad \theta(a) = E_W\{E[Y|A=a,W]\}$$

where A is alcohol outlet density and it is set to the value a, W is the vector of confounders, and Y is binge drinking. We calculated robust confidence intervals for all (pointwise) parameter estimates by using a nonparametric bootstrap.[53] Results are presented in a figure because smooths are not well represented in tables.

RESULTS

The survey respondents were demographically similar to the overall population of New York City according to the 2000 Census, with 38.2% White, 27.0% African American, 5.1% Asian, 27.2% Hispanic, and 2.5% of other racial groups. Mean age was 45 years (range = 18–94), 51.1% of respondents were female, and 39.2% were born outside the United States. Binge drinking was reported by 8.6% of respondents. A full description of the sample is provided in Table 1.

Examination of neighborhood alcohol outlet density suggested there were no outliers; the mean density was 61 outlets per square mile with a range of 5 to 132. Fewer than 1% of respondents had propensity values that were more extreme (higher or lower) than the maximum or minimum propensity values among respondents living in neighborhoods with the other exposure value (propensity distributions available from the corresponding author), suggesting that analyses did not rely on extrapolation.

In bivariable analysis, higher neighborhood outlet density was associated with higher prevalence of binge drinking. From the lowest to highest quarters of alcohol outlet density, the prevalences of binge drinking were 7.2%, 7.6%, 8.4%, and 11.8 ($P < .01$). Most demographic and socioeconomic characteristics and history of drinking were associated with binge drinking in bivariable analysis (Table 1).

Figure 1 depicts results from marginal models based on the generalized additive model analysis of the relation between neighborhood alcohol outlet density and binge drinking with adjustment for confounders including demographic and socioeconomic characteristics, neighborhood median income, and history of drinking. This figure presents the estimated prevalence of binge drinking (y-axis) if all residents had lived in neighborhoods with alcohol outlet density set to levels across the range of the alcohol outlet density in the data (x-axis; i.e.,$\hat{\theta}(a)$). The shape of the relation is markedly nonlinear, with a stronger relation

TABLE 1—New York Social Environment Study Characteristics and Bivariable Associations With Binge Drinking: 2005

	NYSES Population, No. (%)	2000 Census, New York City, %	Binge Drinking No. (%)	Binge Drinking P^a
Total	4000 (100.0)	100.0	342 (8.6)	
Age, y				<.01
18–24	350 (11.8)	13.2	53 (15.8)	
25–34	685 (18.1)	22.5	108 (14.7)	
35–44	815 (19.5)	20.8	84 (9.6)	
45–54	808 (21.4)	16.7	47 (4.9)	
55–64	612 (14.9)	11.3	33 (5.4)	
≥ 65	690 (14.4)	15.5	16 (2.5)	
Race/ethnicity				<.01
White	1616 (38.2)	38.7	168 (11.1)	
African American	1055 (27.0)	23.0	77 (6.6)	
Asian	164 (5.1)	10.1	14 (7.5)	
Hispanic	958 (27.2)	24.7	70 (7.6)	
Other	95 (2.5)	3.6	8 (6.2)	
Gender				<.01
Male	1880 (48.9)	46.2	203 (10.7)	
Female	2120 (51.1)	53.8	139 (6.5)	
Marital status				<.01
Married	1632 (47.3)		110 (6.6)	
Divorced	479 (9.6)		41 (7.6)	
Separated	208 (4.7)		17 (7.7)	
Widowed	354 (6.7)		13 (3.7)	
Never married	1270 (31.7)		160 (13.1)	
Birthplace				<.01
New York City	1810 (44.7)		170 (9.7)	
Other US location	731 (16.1)		85 (12.9)	
Different country	1406 (39.2)		86 (5.7)	
Interview language				.02
English	3545 (86.6)		321 (9.1)	
Spanish	455 (13.4)		21 (5.1)	
Education				.17
< high school	508 (13.9)		37 (7.5)	
High school or GED	923 (24.7)		74 (8.5)	
Some college	879 (23.2)		82 (9.0)	
College graduate	883 (21.6)		92 (10.5)	
Graduate work	730 (16.6)		54 (6.9)	
Income, $				<.01
≤ 40 000	1605 (39.7)		127 (8.0)	
40 001–80 000	1093 (27.3)		116 (10.5)	
> 80 000	722 (18.4)		77 (10.8)	
Missing	580 (14.6)		22 (3.6)	
Unemployed				<.01
No	3658 (91.5)		303 (8.1)	
Yes	321 (8.5)		39 (13.5)	

Continued

TABLE 1—*Continued*

Years lived in neighborhood			<.01
< 8	1330 (34.4)	155 (11.0)	
8–21	1318 (34.0)	115 (8.8)	
> 21	1335 (31.6)	72 (5.8)	
Drinking before moved to neighborhood			<.01
Ever drank or tried drinking	706 (17.4)	12 (1.6)	
Monthly drinker	1948 (45.8)	245 (12.6)	
Never drank	1346 (36.8)	85 (6.8)	
Neighborhood median income			.08
Q1	778 (18.8)	81 (10.6)	
Q2	1075 (27.9)	80 (7.4)	
Q3	1089 (28.7)	82 (7.6)	
Q4	1058 (24.6)	99 (9.5)	
Neighborhood alcohol outlet density			<.01
Q1	1066 (28.7)	75 (7.2)	
Q2	1014 (26.2)	76 (7.6)	
Q3	1023 (24.3)	91 (8.4)	
Q4	897 (20.7)	100 (11.8)	

Note. GED = general equivalency diploma; NYSES = New York Social Environment Study.
[a]*P* values are based on the χ^2 test comparing binge drinking by covariate categories.

between alcohol outlet density and binge drinking at densities of more than 80 outlets per square mile. For example, binge drinking prevalence was estimated to be 13% at 130 outlets per square mile (95% confidence interval [CI] = 9%, 17%), 8% at 80 outlets per square mile (95% CI = 7%, 9%), and 8% at 20 outlets per square mile (95% CI = 6%, 10%).

DISCUSSION

We found a nonlinear relation between alcohol outlet density and binge drinking in New York City; the relation was far stronger at densities of more than 80 outlets per square mile. From a policy perspective, this nonlinearity suggests that reductions in alcohol outlet density where density is highest and the relation is strongest (i.e., the slope is steepest) may have the largest public health impact per unit reduction. The nonlinearity observed in our analysis is consistent with 2 studies that considered the shape of the relation between alcohol outlet density and violence (Melbourne, Australia, and Detroit, MI),[37,38] and 1 recent publication on harmful alcohol consumption in Melbourne, Australia.[39] Although studies that have considered the shape of the relation are few, the similarity of the nonlinear shape (i.e., stronger relation at higher densities) across settings and for different outcomes suggests future observational and intervention research should consider the possibility of a nonlinear shape for the relation between alcohol outlet density and outcomes of interest.

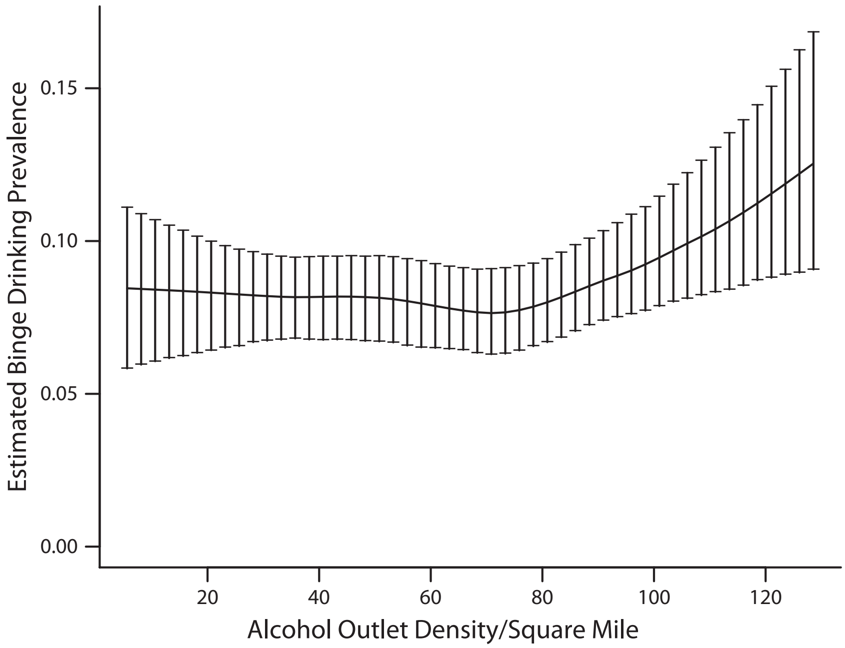
It is worth noting that the level at which alcohol outlet density becomes more strongly associated with harms seems to be quite different between settings. For example, the study of alcohol outlet density and harmful consumption in Melbourne, Australia, found that the nonlinear shape was suggested by a stronger association for the category of 8 or more outlets per square kilometer, which is equivalent to 21 or more per square mile; information is not presented on the range of densities in this category, but it is unlikely that it reaches the densities found in our study of New York City that found a slope increase with more than 80 outlets per square mile. Melbourne is a large city (approximately 4 to 5 million population) but is more car transit–oriented than New York City. New York City is larger (approximately 8 million population) with walking and public transit as more dominant modes of transportation, and, thus, similar densities in these 2 different cities may translate to different degrees of access to outlets. In general, this suggests the inflection point for a nonlinear relation may be context-specific, limiting ability to provide general guidance on the point at which density becomes more harmful.

Limitations and Strengths

There are several limitations to this study. The cooperation percentage was 54%, which is consistent with many other recent telephone-based studies.[54] However, this cooperation percentage does raise concern about how well the study sample represents the city of New York. Participants were informed that they would be participating in a "survey about the neighborhoods where New Yorkers live and what people think about their neighborhoods," and, thus, they were not likely to refuse on the basis of binge drinking. As described previously, rules prohibited random digit dialing to cell phones in 2005, and, thus, we were unable to contact the 5% of households that were cell phone–only at that time. The distribution of demographic characteristics such as age, race, and gender is very similar to the 2000 Census data for New York City (Table 1). However, the individuals we were able to reach and who agreed to participate may still differ from those in the city overall in ways that we were unable to capture.

We calculated the neighborhood alcohol outlet density measure for community districts; although these are meaningful units, residents on the edges of community districts may also be influenced by alcohol outlet density in adjacent areas. Self-report is standard practice in alcohol research and telephone interviews are thought to elicit more accurate reports than in-person interviews[55]; however, there may be differences between actual binge drinking and reported binge drinking. In this study we focused on off-premises alcohol outlet density; although alcohol is certainly available through other means (e.g., restaurants), off-premises outlet density is the measure that is consistently associated with societal harms and alcohol consumption in past research.

Among several strengths, this study included a large population-based sample. We assessed alcohol outlet density based on records kept by



Note. Estimate binge drinking was determined by $\theta(a) = E_W\{E[Y|A = a, W]\}$, where *A* is alcohol outlet density and it is set to the value *a*, *W* is the vector of confounders, and *Y* is binge drinking. Whiskers indicate 95% confidence intervals.

FIGURE 1—Estimated prevalence of binge drinking with alcohol outlet density set to levels across the range of the data.

the State Liquor Authority and, thus, it was not influenced by respondent perception. Social selection has been considered one of the major barriers to determining whether the environment has an influence on people, or whether people who have worse health "drift" or select into worse types of environments.[51,56] We accounted for 1 potential contributor to social selection by adjusting for history of drinking before each person's residence in his or her current neighborhood. Associations observed were not attributable to an effect of people with certain drinking histories being likely to move to high–alcohol outlet density neighborhoods. We explicitly considered the shape of the relation between alcohol outlet density and binge drinking to better inform policy and intervention planning.

An association observed between alcohol outlet density and binge drinking does not necessarily represent how binge drinking might change following a policy or intervention that reduces alcohol outlet density—this is one of the greatest challenges in the interpretation of neighborhood research.[50,56,57] The assumptions necessary for causal interpretation of associations in observational research generally and observational neighborhood research specifically have been well-elaborated elsewhere.[58,59] In brief, exposure must precede the outcome (temporal ordering), all confounders must be controlled (ignorability), exposures in one neighborhood cannot affect the potential outcomes of individuals in other neighborhoods (neighborhood-level stable unit treatment value assumption), and the outcomes observed for a given exposure value must reflect those that would have been observed if the exposure had been counterfactually assigned to that value (consistency assumption).

Because of the cross-sectional design of our study, we cannot establish temporal ordering between the exposure and outcome. For a causal interpretation we must assume that alcohol outlet density comes before binge drinking; this is a reasonable assumption, but the reverse may also be true to some extent. Were this assumption untrue, we would infer the wrong causal direction for the parameter estimated. Longitudinal consideration of these relations will be necessary to establish that temporal relation and improve the potential for causal interpretation.

Although we controlled many confounders, notably including history of drinking before residence in the current neighborhood, ignorability cannot be assessed empirically and can only ever be approximated with observational data. The stability assumption is not unreasonable for the alcohol outlet density exposure because the density in one area does not seem likely to affect potential outcomes in another area.

Conclusions

Ultimately, with the challenges of inferring causal effects from observational studies on alcohol outlet density, it will be critical for future research to assess the impact of policies and interventions that aim to reduce alcohol outlet density, and for those assessments to consider nonlinearity in effects. Now that a wide range of policymaking bodies have recommended intervention to reduce alcohol outlet density, there will be more opportunities to assess policy impacts. Explicit examination of the shape of policy effects is important because we need to know whether interventions are most effective if targeted to high-density areas, or are equally effective for all areas. ■

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Contributors

J. Ahern collaborated on the design and implementation of the study, designed the analysis, conducted the literature review, and wrote the article. C. Margerison-Zilko collaborated on the analysis plan and literature review, and substantially edited all sections of the article. A. Hubbard collaborated on the design of the analysis, implemented the analysis, and provided input on the article. S. Galea obtained study funding, collaborated on the design and implementation of the study, and substantially edited all sections of the article. All authors have approved the final version of the article.

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Human Participant Protection

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