Examination of Cross-Sectional Associations of Neighborhood Deprivation and Alcohol Outlet Density With Hazardous Drinking Using a Twin Design

ISAAC C. RHEW, PH.D., M.P.H.,[a,*] RICK KOSTERMAN, PH.D.,[b] GLEN E. DUNCAN, PH.D., R.C.E.P.,[c] & CHRISTINA MAIR, PH.D., M.P.H.[d]

[a]*Center for the Study of Health and Risk Behaviors, Department of Psychiatry and Behavioral Sciences, University of Washington, Seattle, Washington*

[b]*Social Development Research Group, University of Washington, Seattle, Washington*

[c]*Washington State Twin Registry, Washington State University, Spokane, Washington*

[d]*Department of Behavioral and Community Health Sciences, University of Pittsburgh Graduate School of Public Health, Pittsburgh, Pennsylvania*

ABSTRACT. Objective: The purpose of this study was to examine whether neighborhood socioeconomic deprivation and alcohol outlet density are associated with hazardous drinking using a co-twin design to control for confounding because of genetic and shared environmental factors. **Method:** The study sample included cross-sectional data from 1,996 same-sex adult twin pairs (mean age = 36.6; 65.9% female) from the Washington State Twin Registry. The Singh Index was used to characterize neighborhood social deprivation for participants' census tract of residence. Geocoded alcohol outlet data were used to create a measure of census tract alcohol outlet density. The three-item Alcohol Use Disorders Identification Test–Consumption scale (AUDIT-C) was used to measure the level of hazardous drinking. Poisson mixed-effects models were used to examine associations between neighborhood factors and AUDIT-C score. Covariates included household income, level of education completed, non-White race, sex, and rurality of residence. **Results:** Accounting for covariates, there was a statistically significant within-pair association between neighborhood socioeconomic deprivation and a higher level of hazardous drinking. There was no within-pair association between the density of alcohol outlets and hazardous drinking. Associations did not differ by zygosity. **Conclusions:** The socioeconomic conditions of the neighborhood may play an important role in the development of alcohol misuse even after accounting for genetic and shared environmental influences. Twin designs may be a promising complementary approach to investigating the role of neighborhood characteristics on alcohol and substance use. Further research is needed to better understand the ways through which and for whom neighborhood characteristics may influence hazardous drinking. (*J. Stud. Alcohol Drugs, 79,* 68–73, 2018)

THERE HAS BEEN LONG-STANDING INTEREST in the influence of neighborhood contextual factors on alcohol use and related problems (Karriker-Jaffe, 2011; Watts & Rabow, 1983). Two neighborhood-level characteristics thought to influence alcohol use are socioeconomic deprivation and alcohol outlet density. Although not entirely consistent, studies have shown that indicators of neighborhood deprivation are associated with increased alcohol use and problems (Cerdá et al., 2010; Rudolph et al., 2013; Stimpson et al., 2007). There is also evidence for effects of alcohol outlet density on alcohol use and related problems. A greater density of alcohol outlets (i.e., on-premise outlets that sell alcohol for consumption onsite, such as bars and restaurants, and off-premise outlets that sell for offsite consumption, such as liquor stores) may affect heavy drinking through increasing alcohol availability, may create core groups of problem drinkers through niche assortment (Gruenewald, 2007), or may simply be a marker of socially disorganized neighborhood environments. Ecological studies have consistently shown associations between higher outlet density and alcohol consumption and other problems such as drinking and driving, violence, and crime (Gruenewald, 2007). Despite some contrasting findings (Pollack et al., 2005), evidence is available from multilevel studies as well (e.g., Brenner et al., 2015a, 2015b; Gruenewald et al., 2014; Theall et al., 2011).

Although most studies on neighborhood factors and alcohol focus on the frequency and/or amount of alcohol consumption, fewer studies have examined indicators of hazardous drinking or disordered use as an outcome (e.g., Ahern et al., 2015). Because of the physical and psychological risks associated with hazardous drinking (Reid et al., 1999), research is also necessary on the potential role of neighborhood context on indicators of hazardous or disordered alcohol use.

Despite emerging evidence linking neighborhood contextual factors and alcohol use, causal inference remains hampered because of unmeasured factors associated with neighborhood self-selection that could lead to potential

Received: December 28, 2016. Revision: June 19, 2017.

This work was supported by two grants from the National Institutes of Health (R01 AG042176 awarded to Glen Duncan and R01DA033956 awarded to Rick Kosterman) and Grant A101837 from the University of Washington Royalty Research Fund. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies.

*Correspondence may be sent to Isaac C. Rhew at the Center for the Study of Health and Risk Behaviors, Department of Psychiatry and Behavioral Sciences, University of Washington, 1100 NE 45th St., #300, Seattle, WA 98105, or via email at: rhew@uw.edu.

bias attributable to nonrandom sorting. One promising and complementary approach to more traditional designs is the use of twin designs that overcome the potential for genetic and shared environment confounding (Duncan et al., 2014). Any within-twin-pair associations cannot be attributed to genetics in monozygotic (MZ) twins or to common family of origin and upbringing factors (e.g., parents' use of and attitudes toward alcohol use) in MZ and dizygotic (DZ) twins, although other important factors that make twins within a pair different would still need to be accounted for. Studies of neighborhood effects have used this twin design for outcomes including physical activity, depression, and substance use, among others (Cohen-Cline et al., 2015; Duncan et al., 2015; Kendler et al., 2014).

The aim of this study was to examine whether neighborhood socioeconomic deprivation and alcohol outlet density are cross-sectionally associated with hazardous drinking using an adult twin sample to control for confounding by genetic and shared (familial) factors that would otherwise confound statistical associations among unrelated individuals.

Method

Study participants

Participants in this study were enrolled in the Washington State Twin Registry (WSTR) (formerly the University of Washington Twin Registry). Details about registry construction have been described elsewhere (Afari et al., 2006; Strachan et al., 2013). Briefly, the WSTR is a community-based sample of adult MZ and DZ twin pairs reared together who have been identified through Washington State Department of Licensing records since 1999. Participating twins completed a survey with items regarding sociodemographics, general physical and mental health, and health behaviors. Twins were classified as MZ or DZ based on standard questions that have been shown to have greater than 90% accuracy when compared with DNA-based methods (Spitz et al., 1996). Participant residences were geocoded for those enrolled in 2008 or later. Because there were changes in Washington State legislation that took effect in 2012 that allowed for privatization of liquor sales, which affected alcohol outlet availability and spatial distribution, participants enrolled after June 2012 were not included. Thus, this study included participants who completed the study survey between 2008 and 2012 and whose residence was geocoded. This sample was further restricted to 2,130 same-sex pairs who were both living in Washington State, where finer grain data on alcohol outlet locations were available.

Measures

To obtain neighborhood measures, geocoded participant residences at the time of the survey were linked to census tracts. Participants resided in 1,189 census tracts with a mean of 3.4 participants per tract (range: 1–17).

The area-based Singh index was used to assess neighborhood social deprivation (Singh, 2003; Stimpson et al., 2007). A factor score was derived from 17 census tract–level indicators, including percentage living in poverty, educational attainment, employment status, median household income, car ownership, and crowding. The full list of variables used for the derivation of the index and their distributions are available in online supplemental information. The Singh index factor score was standardized, with higher scores indicative of greater deprivation.

The Washington State Liquor and Cannabis Board provided addresses for on- and off-premise outlets (both state-run hard liquor stores and stores that sold beer and wine) with active licenses in each of the years 2008 through 2012. These outlets were geocoded with a 100% match rate and used to create spatial measures for the density of on- and off-premise outlets per square kilometer within the participant's census tract of residence. Because the densities of on- and off-premise outlets were highly correlated (Spearman's $\rho = .79$), for primary analyses we used the total density of any type of outlet. For ease of interpretation, the outlet density variable was divided by 3.36, which represents the interquartile range.

The Alcohol Use Disorders Identification Test–Consumption scale (AUDIT-C) was used in the WSTR surveys to assess hazardous drinking (Bush et al., 1998). The AUDIT-C was developed to identify individuals with hazardous patterns of alcohol consumption and potential alcohol use disorder. Items ask about the frequency of any drinking, typical number of drinks consumed when drinking, and frequency of heavy drinking. This scale has strong psychometric properties with high test–retest reliability and criterion validity when assessed against clinical diagnoses for alcohol abuse or dependence according to criteria from the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV; American Psychiatric Association, 1994), as well as the DSM-5 (American Psychiatric Association, 2013) AUD in population-based samples (Dawson et al., 2005, 2012).

Additional covariates obtained from the survey included sex, annual household income, highest level of education completed, and race/ethnicity (0 = *White,* 1 = *non-White*). An indicator for rurality (<1,000 persons per square mile within one's census tract) was also assessed as an additional neighborhood-level covariate.

Analytic plan

To account for clustering of individuals within twin pairs and within census tracts, generalized mixed-effects models with separate random intercepts for twin pair and census tract of residence were used to examine associations between the neighborhood characteristics and the AUDIT-C score. Sensitivity analyses were also conducted to explore the possibility of further within-county correlation by specifying an additional random intercept for county. Between-county variance was minimal (county-level intercept *SD* < .001), and thus we present results from models without the county random intercept.

The AUDIT-C score is a nonnegative integer that displayed a positive skew. Thus, it was treated as a count by specifying a Poisson distribution. Likelihood ratio tests indicated that inclusion of an overdispersion term did not significantly improve model fit. Coefficients from count regression models are typically exponentiated to yield count ratios (CRs; also referred to as rate ratios) that describe the proportional change in the count associated with a 1-unit increase in the covariate (Atkins et al., 2013).

Because of the computational challenges associated with a generalized model with multiple random intercepts, a Bayesian Markov chain Monte Carlo (MCMC) form of the mixed-effects model was used to estimate the CRs and the 95% credible interval (CI) from the posterior probability distribution (Dunson, 2001; Hamra et al., 2013). Noninformative priors were used and we specified 1,205,000 interations with a 5,000 sample burn-in and a thinning interval of 1,200. The effective sample size for each of the neighborhood covariates was 1,000. Gelman–Rubin diagnostic tests and visualization of trace plots indicated convergence of the models.

To remove potential confounding by factors shared by twins, models included two separate variables for the neighborhood characteristics of interest: (a) the mean of the neighborhood factor of interest, $\overline{Nei_i}$, for the two twins within each pair *i,* and (b) the individual deviation from the twin-pair mean, $Nei_{ij} - \overline{Nei_i}$, for twin *j* (Carlin et al., 2005). This within-pair deviation is the primary parameter of interest, as it reflects the "effect" of the neighborhood characteristic not subject to genetic or shared environment confounding. All models included covariates for sex (0 = *male,* 1 = *female*), annual household income (ordinal variable from 1 [*<$20,000*] to 8 [*≥$80,000*]), race, level of education (ordinal variable from 1 [*<9th grade*] to 8 [*graduate or profession degree*]), and rurality (0 = *urban,* 1 = *rural*).

Three primary models were performed and adjusted for the demographic covariates: Model 1 examined the twin-mean and individual deviation from the twin-mean of neighborhood deprivation covariates, Model 2 examined the twin-mean and deviation from the twin-mean of alcohol outlet density, and Model 3 included both the neighborhood deprivation and alcohol outlet density variables. Additional sensitivity analyses examined on- and off-premise outlets separately and different spatial scales (e.g., 1- and 2-km road network buffer, proximity to nearest outlet).

Additional models examined interactions between the twin's deviation from the twin-pair mean and zygosity. Although both MZ and DZ twin pairs control equally for confounding because of common childhood environment, DZ twin pairs only control for half of genetic confounding. Thus, a statistically significant interaction indicating that the within-pair parameter for the neighborhood feature is stronger for DZ compared with MZ twins would suggest genetic confounding.

Analyses were conducted with R statistical software (R Core Team, 2012), Version 3.2.1, using the "MCMCglmm" package to perform the models (Hadfield, 2010).

Results

Of the 2,130 same-sex pairs in the initial sample, 134 had missing data on variables used in analyses, including AUDIT-C score, household income, and education. Thus, data from 1,996 (93.7%) twin pairs (*N* = 3,992 individuals) were used for analyses. The geographic distribution of the sample was representative of Washington State, with all 39 counties represented and 52.7% coming from the 3 most populated counties, which is consistent with the proportion observed in the 2010 census (51.2%). The mean AUDIT-C score was 2.5 (*SD* = 2.4; range: 0–12), the mean Singh neighborhood deprivation score was -.003 (*SD* = 0.9; range: -2.3–4.2), and the mean census tract density of outlets per square kilometer was 3.9 (*SD* = 11.8; range: 0–178.3). There was a moderate correlation between neighborhood deprivation and outlet density (Spearman's ρ = .24). The distribution of demographic characteristics is available in the online supplemental information.

Table 1 shows count ratios and credible intervals for AUDIT-C score according to covariates. Before inclusion of outlet density, there was a statistically significant within-pair association between neighborhood deprivation and hazardous drinking such that a 1-unit higher deviation from the twin-pair mean was associated with an 7% increase in AUDIT-C score (CR = 1.066, 95% CI [1.013, 1.127]) adjusting for covariates (Model 1). In contrast, without inclusion of neighborhood deprivation, there was no statistically significant within-pair association between outlet density and hazardous drinking (Model 2). When including both neighborhood characteristics in the same model (Model 3), the within-pair association between neighborhood deprivation and AUDIT-C score remained statistically significant, and there was still no significant within-pair association for outlet density. Sensitivity analyses examining off- versus on-premise outlet density separately and different spatial scales also did not show any statistically significant within-pair associations with hazardous drinking (data not shown).

When examining potential modifying effects of zygosity, we did not observe any statistically significant interactions with either of the neighborhood characteristics.

Discussion

This study sought to take advantage of the twin design to examine the role of neighborhood factors for alcohol misuse.

TABLE 1. Count ratios (CRs) and their 95% credible intervals (CIs) from Bayesian Markov Chain Monte Carlo Poisson mixed models for Alcohol Use Disorders Identification Test–Consumption (AUDIT-C) score according to covariates

	Model 1			Model 2			Model 3		
Covariate	CR	[95% CI]	*p*	CR	[95% CI]	*p*	CR	[95% CI]	*p*
Within-pair deviation in neighborhood deprivation	1.066	[1.013, 1.127]	.022	–	–	–	1.069	[1.014, 1.129]	.018
Twin pair mean neighborhood deprivation	0.957	[0.910, 1.009]	.112	–	–	–	0.940	[0.891, 0.993]	.034
Within-pair deviation in outlet density	–	–	–	1.005	[0.997, 1.015]	.246	1.003	[0.994, 1.012]	.606
Twin pair mean of outlet density	–	–	–	1.038	[1.25, 1.052]	<.001	1.040	[1.025, 1.054]	<.001
Female sex	0.748	[0.678, 0.803]	<.001	0.744	[0.683, 0.804]	<.001	0.750	[0.692,0 .814]	<.001
Non-White race	0.762	[0.685, 0.849]	<.001	0.751	[0.674, 0.839]	<.001	0.758	[0.681, 0.835]	<.001
Household income	0.990	[0.977, 1.002]	.120	0.992	[0.981, 1.003]	.178	0.990	[0.979, 1.002]	.116
Highest level of education	1.059	[1.040, 1.080]	<.001	1.056	[1.038, 1.078]	<.001	1.053	[1.036, 1.077]	<.001
Rural	0.894	[0.823, 0.955]	.002	0.912	[0.851, 0.976]	.002	0.925	[0.856, 0.992]	.046
Random effects	*SD*	[95% CI]		*SD*	[95% CI]		*SD*	[95% CI]	
Census tract intercept	.022	[<.001, .043]		.019	[<.001, .038]		.019	[<.001, .037]	
Twin pair intercept	.549	[.484, .611]		.540	[.475, .604]		.541	[.473, .598]	
DIC	14,792.68			14,788.12			14,782.10		

Notes: p = posterior probability of CR < 1 (if CR > 1) or > 1 (if CR < 1); DIC = deviance information criterion.

Results showed a cross-sectional association between neighborhood deprivation and hazardous drinking that was not attributable to genetic or shared environment confounding. However, there was no within-pair association between overall alcohol outlet density and alcohol use and misuse. This study thus provides further evidence suggestive of the role of neighborhood disadvantage in alcohol misuse (Cerdá et al., 2010; Karriker-Jaffe, 2011). Plausible mechanisms exist through which neighborhood deprivation could lead to alcohol misuse. For example, disadvantaged neighborhoods may lack material and social resources to buffer individuals from common psychosocial stressors and give rise to environmental stressors such as crime and other forms of disorder because of a lack of neighborhood-level social cohesion and control (Sampson & Raudenbush, 2004), which may prompt residents to misuse alcohol to cope with stress (Boardman et al., 2001). Further, disadvantaged environments may have injunctive norms that are more acceptable of hazardous drinking (Scribner et al., 2000).

This study found no within-pair association between outlet density and hazardous drinking. Hazardous drinking or disordered use may not be as sensitive to alcohol outlet density as other alcohol-related outcomes such as frequency of alcohol consumption, interpersonal violence, and drinking and driving (Gruenewald & Remer, 2006; Gruenewald et al., 2014; Ponicki et al., 2013; Scribner et al., 1995). It is also possible that the lack of a within-pair association may be related to greater legal constraints on alcohol sales in Washington State compared with most other states. At the time of the survey, Washington regulated the number and locations of state-run liquor stores. More diverse outlet concentrations and distributions could increase variability in outlet density and increase the potential for detecting a within-pair association. Further, retail establishments may be inclined to market to niche groups that could concentrate higher risk drinkers in certain areas (Gruenewald, 2007). State regulation of off-premise outlets could hinder such processes.

There were important limitations to this study. This study was cross-sectional and it was not possible to assess temporal ordering. Although this study accounted for potential genetic influences and shared upbringing, there may have been unmeasured confounders at the individual and/or neighborhood level during adulthood that are unique to each twin, beyond education and household income, that could have accounted for the within-pair association between neighborhood deprivation and hazardous drinking. The hazardous drinking measure was based on a brief three-item scale rather than a more comprehensive instrument. Although studies have observed important moderation of associations between neighborhood disadvantage and alcohol outcomes by race (Karriker-Jaffe et al., 2012), this study's low proportion of non-White individuals prohibited us from adequately examining this. Although census tracts have been widely used in research, these boundaries may not reflect meaningful neighborhoods. Finally, the environments in which routine activities occur may place individuals in situations that increase the likelihood that deviant behavior, such as disordered drinking, could occur (Freisthler et al., 2004; Osgood et al., 1996). This study did not link the broader range of spaces and environmental characteristics that an individual interacts with throughout one's regular activities, whether within one's residential neighborhood or beyond.

Conclusions

This study showed a cross-sectional association between neighborhood socioeconomic deprivation and hazardous drinking that was not due to genetic or shared environment factors, providing additional support for the role of neighborhood contextual factors in the development of alcohol problems. Building on existing work identifying environmental strategies for reducing excessive drinking such as restricting hours and days of alcohol sales (Popova et al., 2009) and limiting price promotions (Babor et al., 1978), future research may be warranted to consider other macro-social mechanisms such as neighborhood drinking norms and collective efficacy (Ahern et al., 2008). Further, it is possible that associations between neighborhood deprivation and alcohol misuse may depend on other factors, including genetic susceptibility to alcohol misuse. Emerging evidence suggests a potential gene-by-neighborhood environment interplay for other health outcomes (Horn et al., 2015; Strachan et al., 2017). Future research can capitalize on the twin design to investigate similar questions pertaining to alcohol use.

Acknowledgments

The authors thank Charles Fleming for his helpful comments on a previous version of the manuscript, Marc Siegfried at the Washington State Liquor and Cannabis Board for his assistance with obtaining location data for alcohol outlets, and Matt Dunbar and Michael Babb for their assistance with creation of alcohol outlet density measures.

References

Afari, N., Noonan, C., Goldberg, J., Edwards, K., Gadepalli, K., Osterman, B., . . . Buchwald, D. (2006). University of Washington Twin Registry: Construction and characteristics of a community-based twin registry. *Twin Research and Human Genetics, 9,* 1023–1029. doi:10.1375/twin.9.6.1023

Ahern, J., Balzer, L., & Galea, S. (2015). The roles of outlet density and norms in alcohol use disorder. *Drug and Alcohol Dependence, 151,* 144–150. doi:10.1016/j.drugalcdep.2015.03.014

Ahern, J., Galea, S., Hubbard, A., Midanik, L., & Syme, S. L. (2008). Culture of drinking and individual problems with alcohol use. *American Journal of Epidemiology, 167,* 1041–1049. doi:10.1093/aje/kwn022

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: Author.

Atkins, D. C., Baldwin, S. A., Zheng, C., Gallop, R. J., & Neighbors, C. (2013). A tutorial on count regression and zero-altered count models for longitudinal substance use data. *Psychology of Addictive Behaviors, 27,* 166–177. doi:10.1037/a0029508

Babor, T. F., Mendelson, J. H., Greenberg, I., & Kuehnle, J. (1978). Experimental analysis of the "happy hour": Effects of purchase price on alcohol consumption. *Psychopharmacology, 58,* 35–41. doi:10.1007/BF00426787

Boardman, J. D., Finch, B. K., Ellison, C. G., Williams, D. R., & Jackson, J. S. (2001). Neighborhood disadvantage, stress, and drug use among adults. *Journal of Health and Social Behavior, 42,* 151–165. doi:10.2307/3090175

Brenner, A. B., Borrell, L. N., Barrientos-Gutierrez, T., & Diez Roux, A. V. (2015a). Longitudinal associations of neighborhood socioeconomic characteristics and alcohol availability on drinking: Results from the Multi-Ethnic Study of Atherosclerosis (MESA). *Social Science & Medicine, 145,* 17–25. doi:10.1016/j.socscimed.2015.09.030

Brenner, A. B., Diez Roux, A. V., Barrientos-Gutierrez, T., & Borrell, L. N. (2015b). Associations of alcohol availability and neighborhood socioeconomic characteristics with drinking: Cross-sectional results from the Multi-Ethnic Study of Atherosclerosis (MESA). *Substance Use & Misuse, 50,* 1606–1617. doi:10.3109/10826084.2015.1027927

Bush, K., Kivlahan, D. R., McDonell, M. B., Fihn, S. D., & Bradley, K. A. (1998). The AUDIT alcohol consumption questions (AUDIT-C): An effective brief screening test for problem drinking. *Archives of Internal Medicine, 158,* 1789–1795. doi:10.1001/archinte.158.16.1789

Carlin, J. B., Gurrin, L. C., Sterne, J. A. C., Morley, R., & Dwyer, T. (2005). Regression models for twin studies: A critical review. *International Journal of Epidemiology, 34,* 1089–1099. doi:10.1093/ije/dyi153

Cerdá, M., Diez-Roux, A. V., Tchetgen, E. T., Gordon-Larsen, P., & Kiefe, C. (2010). The relationship between neighborhood poverty and alcohol use: Estimation by marginal structural models. *Epidemiology, 21,* 482–489. doi:10.1097/EDE.0b013e3181e13539

Cohen-Cline, H., Turkheimer, E., & Duncan, G. E. (2015). Access to green space, physical activity and mental health: A twin study. *Journal of Epidemiology and Community Health, 69,* 523–529. doi:10.1136/jech-2014-204667

Dawson, D. A., Grant, B. F., Stinson, F. S., & Zhou, Y. (2005). Effectiveness of the derived Alcohol Use Disorders Identification Test (AUDIT-C) in screening for alcohol use disorders and risk drinking in the US general population. *Alcoholism: Clinical and Experimental Research, 29*, 844–854. doi:10.1097/01.ALC.0000164374.32229.A2

Dawson, D. A., Smith, S. M., Saha, T. D., Rubinsky, A. D., & Grant, B. F. (2012). Comparative performance of the AUDIT-C in screening for DSM-IV and DSM-5 alcohol use disorders. *Drug and Alcohol Dependence, 126,* 384–388. doi:10.1016/j.drugalcdep.2012.05.029

Duncan, G. E., Cash, S. W., Horn, E. E., & Turkheimer, E. (2015). Quasi-causal associations of physical activity and neighborhood walkability with body mass index: A twin study. *Preventive Medicine, 70,* 90–95. doi:10.1016/j.ypmed.2014.11.024

Duncan, G. E., Mills, B., Strachan, E., Hurvitz, P., Huang, R., Moudon, A. V., & Turkheimer, E. (2014). Stepping towards causation in studies of neighborhood and environmental effects: How twin research can overcome problems of selection and reverse causation. *Health & Place, 27,* 106–111. doi:10.1016/j.healthplace.2014.02.008

Dunson, D. B. (2001). Commentary: Practical advantages of Bayesian analysis of epidemiologic data. *American Journal of Epidemiology, 153,* 1222–1226. doi:10.1093/aje/153.12.1222

Freisthler, B., Midanik, L. T., & Gruenewald, P. J. (2004). Alcohol outlets and child physical abuse and neglect: Applying routine activities theory to the study of child maltreatment. *Journal of Studies on Alcohol, 65,* 586–592. doi:10.15288/jsa.2004.65.586

Gruenewald, P. J. (2007). The spatial ecology of alcohol problems: Niche theory and assortative drinking. *Addiction, 102,* 870–878. doi:10.1111/j.1360-0443.2007.01856.x

Gruenewald, P. J., & Remer, L. (2006). Changes in outlet densities affect violence rates. *Alcoholism: Clinical and Experimental Research, 30,* 1184–1193. doi:10.1111/j.1530-0277.2006.00141.x

Gruenewald, P. J., Remer, L. G., & LaScala, E. A. (2014). Testing a social ecological model of alcohol use: The California 50-city study. *Addiction, 109,* 736–745. doi:10.1111/add.12438

Hadfield, J. D. (2010). MCMC methods for multi-response generalized linear mixed models: The MCMCglmm R Package. *Journal of Statistical Software, 33,* 1–22. doi:10.18637/jss.v033.i02

Hamra, G., MacLehose, R., & Richardson, D. (2013). Markov chain Monte Carlo: An introduction for epidemiologists. *International Journal of Epidemiology, 42,* 627–634. doi:10.1093/ije/dyt043

Horn, E. E., Turkheimer, E., Strachan, E., & Duncan, G. E. (2015). Behavioral and environmental modification of the genetic influence on body mass index: A twin study. *Behavior Genetics, 45,* 409–426. doi:10.1007/s10519-015-9718-6

Karriker-Jaffe, K. J. (2011). Areas of disadvantage: A systematic review of effects of area-level socioeconomic status on substance use outcomes. *Drug and Alcohol Review, 30,* 84–95. doi:10.1111/j.1465-3362.2010.00191.x

Karriker-Jaffe, K. J., Zemore, S. E., Mulia, N., Jones-Webb, R., Bond, J., & Greenfield, T. K. (2012). Neighborhood disadvantage and adult alcohol outcomes: Differential risk by race and gender. *Journal of Studies on Alcohol and Drugs, 73,* 865–873. doi:10.15288/jsad.2012.73.865

Kendler, K. S., Ohlsson, H., Sundquist, K., & Sundquist, J. (2014). The causal nature of the association between neighborhood deprivation and drug abuse: A prospective national Swedish co-relative control study. *Psychological Medicine, 44,* 2537–2546. doi:10.1017/S0033291713003048

Osgood, D. W., Wilson, J. K., O'Malley, P. M., Bachman, J. G., & Johnston, L. D. (1996). Routine activities and individual deviant behavior. *American Sociological Review, 61,* 635–655. doi:10.2307/2096397

Pollack, C. E., Cubbin, C., Ahn, D., & Winkleby, M. (2005). Neighbourhood deprivation and alcohol consumption: Does the availability of alcohol play a role? *International Journal of Epidemiology, 34,* 772–780. doi:10.1093/ije/dyi026

Ponicki, W. R., Gruenewald, P. J., & Remer, L. G. (2013). Spatial panel analyses of alcohol outlets and motor vehicle crashes in California: 1999–2008. *Accident Analysis and Prevention, 55,* 135–143. doi:10.1016/j.aap.2013.03.001

Popova, S., Giesbrecht, N., Bekmuradov, D., & Patra, J. (2009). Hours and days of sale and density of alcohol outlets: Impacts on alcohol consumption and damage: A systematic review. *Alcohol and Alcoholism, 44,* 500–516. doi:10.1093/alcalc/agp054

R Core Team. (2012). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing.

Reid, M. C., Fiellin, D. A., & O'Connor, P. G. (1999). Hazardous and harmful alcohol consumption in primary care. *Archives of Internal Medicine, 159,* 1681–1689. doi:10.1001/archinte.159.15.1681

Rudolph, K. E., Glass, T. A., Crum, R. M., & Schwartz, B. S. (2013). Neighborhood psychosocial hazards and binge drinking among late middle-aged adults. *Journal of Urban Health, 90,* 970–982. doi:10.1007/s11524-013-9790-2

Sampson, R. J., & Raudenbush, S. W. (2004). Seeing disorder: Neighborhood stigma and the social construction of "broken windows." *Social Psychology Quarterly, 67,* 319–342. doi:10.1177/019027250406700401

Scribner, R. A., Cohen, D. A., & Fisher, W. (2000). Evidence of a structural effect for alcohol outlet density: A multilevel analysis. *Alcoholism: Clinical and Experimental Research, 24,* 188–195. doi:10.1111/j. 1530-0277.2000.tb04590.x

Scribner, R. A., MacKinnon, D. P., & Dwyer, J. H. (1995). The risk of assaultive violence and alcohol availability in Los Angeles County. *American Journal of Public Health, 85,* 335–340. doi:10.2105/AJPH.85.3.335

Singh, G. K. (2003). Area deprivation and widening inequalities in US mortality, 1969–1998. *American Journal of Public Health, 93,* 1137–1143. doi:10.2105/AJPH.93.7.1137

Spitz, E., Moutier, R., Reed, T., Busnel, M. C., Marchaland, C., Roubertoux, P. L., & Carlier, M. (1996). Comparative diagnoses of twin zygosity by SSLP variant analysis, questionnaire, and dermatoglyphic analysis. *Behavior Genetics, 26,* 55–63. doi:10.1007/BF02361159

Stimpson, J. P., Ju, H., Raji, M. A., & Eschbach, K. (2007). Neighborhood deprivation and health risk behaviors in NHANES III. *American Journal of Health Behavior, 31,* 215–222. doi:10.5993/AJHB.31.2.10

Strachan, E., Duncan, G., Horn, E., & Turkheimer, E. (2017). Neighborhood deprivation and depression in adult twins: Genetics and gene × environment interaction. *Psychological Medicine, 47,* 627–638. doi:10.1017/S0033291716002622

Strachan, E., Hunt, C., Afari, N., Duncan, G., Noonan, C., Schur, E., . . . Buchwald, D. (2013). University of Washington Twin Registry: Poised for the next generation of twin research. *Twin Research and Human Genetics, 16,* 455–462. doi:10.1017/thg.2012.124

Theall, K. P., Lancaster, B. P., Lynch, S., Haines, R. T., Scribner, S., Scribner, R., & Kishore, V. (2011). The neighborhood alcohol environment and at-risk drinking among African-Americans. *Alcoholism: Clinical and Experimental Research, 35,* 996–1003. doi:10.1111/j.1530-0277.2010.01430.x

Watts, R. K., & Rabow, J. (1983). Alcohol availability and alcohol-related problems in 213 California cities. *Alcoholism: Clinical and Experimental Research, 7,* 47–58. doi:10.1111/j.1530-0277.1983.tb05410.x