Supplementary Appendix

Supplement to: Smart R, Schell TL, Morral AR, et al. Geographic disparities in rising rates of firearm-related homicide. N Engl J Med 2022;387:189-91. DOI: 10.1056/NEJMc2203322

This appendix has been provided by the authors to give readers additional information about the work.

SUPPLEMENTARY APPENDIX

Geographic Disparities in Rising Firearm Homicide Rates

Rosanna Smart, Ph.D.; Terry L. Schell, Ph.D.; Andrew R. Morral, Ph.D.; Nancy Nicosia, Ph.D.

Table of Contents

Data source

Our analyses use mortality information from the National Vital Statistics System (NVSS) Multiple Cause of Death Micro-data files from 2006 to 2019.[1] These data, maintained by the National Center for Health Statistics (NCHS), are compiled from standardized death certificates filed by various jurisdictions throughout the United States. Medical examiners or coroners are required to investigate homicides, and they are typically the agents who complete the manner of death sections of death certificates for these cases.[2] NCHS then uses this information, as well as information on cause of death, to classify deaths using International Classification of Diseases (ICD) codes.

The NVSS files provide the most complete data on deaths in the United States, capturing over 99% of deaths that occur in the country.[3] These data are considered the most reliable source of national homicide data for the U.S.[4,5] The NVSS data are largely complete on the variables used in this study's analysis, however, we imputed a small number of observations (n=711; 0.4%) with missing ethnicity as non-Hispanic, and we dropped a small number of observations (n=78; <0.01%) with missing age.

Firearm homicides were identified based on ICD-10 codes (*U014, X93-X95). Counts of firearm homicides were aggregated by year, state of death occurrence, and demographic strata, where we defined the strata based on the interaction of sex, age group (0-14, 15-24, 25-34, 35-44, 45-54, 65+), race/ethnicity (Black non-Hispanic, White non-Hispanic, Hispanic, American Indian/Alaska Native non-Hispanic, Asian/Pacific Islander non-Hispanic), and urbanicity. Urbanicity was defined based on county of death occurrence using the 2013 National Center for Health Statistics Urban-Rural Classification Scheme for Counties, dichotomized such that large central and large fringe metros were classified as urban, with all other counties classified as nonurban; this definition divides the US population approximately evenly between urban and nonurban counties.

Details of modeling approach

Our final model was a negative binomial regression in which the log of the expected count of firearm homicides among stratum *i* in state *s* at year *t* (Y_{ist}) was modeled as follows.

$$\begin{aligned}\ln(E[Y_{ist}]) = \alpha + \; & \beta_0 female_i + \beta_1^K RACE_i + \beta_2^K AGE_i + \beta_3 rural_i + \gamma_1 D_{1t}(t-2014) + \gamma_2 D_{2t}(t-2014) \\ & + \theta_0 female_i D_{2t}(t-2014) + \theta_1^K RACE_i D_{2t}(t-2014) + \theta_2^K AGE_i D_{2t}(t-2014) \\ & + \theta_3 rural_i D_{2t}(t-2014) + u_{0s} + u_{1s} D_{2t}(t-2014) + \ln(pop_{ist})\end{aligned}$$

where:

- $female_i$ is an indicator for female (male as the reference group)
- $RACE_i$ includes indicators for Black non-Hispanic, Hispanic, American Indian/Alaskan Native non-Hispanic, and Asian/Pacific Islander non-Hispanic (White non-Hispanic as the reference group). Decedents with missing ethnicity (n=711; 0.4%) were categorized as non-Hispanic.
- AGE_i includes indicators for the following age groups: 0-14 years, 25-34 years, 35-44 years, 45-54 years, 65+ years (15-24 years as the reference group). We dropped a small number of observations with missing age (n=78; <0.01%).
- $rural_i$ is an indicator for death occurring in county coded as medium metro, small metro, or non-metro based on the 2013 National Center for Health Statistics Urban-Rural Classification Scheme for Counties (large central and large fringe metros as the reference group).
- D_{1t} is an indicator that takes a value of 1 if year *t* is 2014 or earlier, 0 otherwise.
- D_{2t} is an indicator that takes a value of 1 if year *t* is later than 2014, 0 otherwise.

- u_s is a random intercept for state
- pop_{ist} is the population of strata *i* in state *s* at year *t*, obtained from the Surveillance, Epidemiology, and End Results (SEER) population estimates.

Regression results (see Table S1) are presented in two ways. First, for all demographic and geographic groups, we show the incidence rate ratios (IRRs) and 95% confidence intervals (CIs) for the main effects (i.e., the overall estimated firearm homicide rate ratio comparing each group to the reference group) as well as for the effects interacted with the linear slope over the 2014-2019 period (i.e., the annual change in firearm homicide rates for each group relative to the reference trend). Second, we use the model to compute marginal effects of the firearm homicide rate. These are predictions of the firearm homicide rate for 2014 and for 2019 for each demographic and geographic group, holding all other characteristics at their mean values over the study time period. These effects combine across the main effects and time interactions for each geographic or demographic group and allow for an adjusted comparisons of the change in the firearm homicide rate between 2014 and 2019 as a function of those dimensions.

The adjusted rates for 2014 and 2019 were calculated separately for each demographic and geographic category as follows. After fitting the negative binomial regression model, the expected number of firearm homicide deaths for each category was calculated twice for each level of the categorical variable, once to obtain adjusted 2014 values and once to obtain adjusted 2019 values, while setting all other covariates to their mean value over the study period. For each level of the categorical variable and year (2014 or 2019), we then aggregated up the expected counts and divided by the state-year population (then multiplied by 100,000 to obtain rates expressed per 100,000 population).

For example, for a given state, the 2014 adjusted rate is calculated as:

$$
\begin{aligned}
AR_{s,2014} = {} & \left(\frac{100{,}000}{pop_{s,2014}}\right) \sum_i \exp\Big(\hat{\alpha} + \widehat{\beta_0}\overline{female_i} + \widehat{\beta_1^K}\overline{RACE_i} + \widehat{\beta_2^K}\overline{AGE_i} + \widehat{\beta_3}\overline{rural_i} + \widehat{\gamma_1}(1)(2014-2014) \\
& + \widehat{\gamma_2}(0)(2014-2014) + \widehat{\theta_0}\overline{female_i}(0)(2014-2014) + \widehat{\theta_1^K}\overline{RACE_i}(0)(2014-2014) \\
& + \widehat{\theta_2^K}\overline{AGE_i}(0)(2014-2014) + \widehat{\theta_3}\overline{rural_i}(0)(2014-2014) + u_{0s} + u_{1s}(0)(2014-2014) \\
& + \ln(pop_{is2014})\Big) \\
= {} & \left(\frac{100{,}000}{pop_{s,2014}}\right) \sum_i \exp\left(\hat{\alpha} + \widehat{\beta_0}\overline{female_i} + \widehat{\beta_1^K}\overline{RACE_i} + \widehat{\beta_2^K}\overline{AGE_i} + \widehat{\beta_3}\overline{rural_i} + u_{0s} + \ln(pop_{is2014})\right)
\end{aligned}
$$

Similarly, for a given state, the 2019 adjusted rate is calculated as:

$$
\begin{aligned}
AR_{s,2019} = {} & \left(\frac{100{,}000}{pop_{s,2019}}\right) \sum_i \exp\Big(\hat{\alpha} + \widehat{\beta_0}\overline{female_i} + \widehat{\beta_1^K}\overline{RACE_i} + \widehat{\beta_2^K}\overline{AGE_i} + \widehat{\beta_3}\overline{rural_i} + \widehat{\gamma_1}(0)(2019-2014) \\
& + \widehat{\gamma_2}(1)(2019-2014) + \widehat{\theta_0}\overline{female_i}(1)(2019-2014) + \widehat{\theta_1^K}\overline{RACE_i}(1)(2019-2014) \\
& + \widehat{\theta_2^K}\overline{AGE_i}(1)(2019-2014) + \widehat{\theta_3}\overline{rural_i}(1)(2019-2014) + u_{0s} + u_{1s}(1)(2019-2014) \\
& + \ln(pop_{is2019})\Big) \\
= {} & \left(\frac{100{,}000}{pop_{s,2019}}\right) \sum_i \exp\Big(\hat{\alpha} + \widehat{\beta_0}\overline{female_i} + \widehat{\beta_1^K}\overline{RACE_i} + \widehat{\beta_2^K}\overline{AGE_i} + \widehat{\beta_3}\overline{rural_i} + \widehat{\gamma_2}(5) + \widehat{\theta_0}\overline{female_i}(5) \\
& + \widehat{\theta_1^K}\overline{RACE_i}(5) + \widehat{\theta_2^K}\overline{AGE_i}(5) + \widehat{\theta_3}\overline{rural_i}(5) + u_{0s} + u_{1s}(5) + \ln(pop_{is2019})\Big)
\end{aligned}
$$

For the state-specific adjusted rate estimates shown in Panel C of Figure 1, the adjusted rates (calculated relative to a specific reference category as described above) are rescaled such that the average adjusted rate in 2014 is equal to the observed rate averaged across states in 2014.

Are effects specific to firearm homicides?

We conducted a sensitivity analysis to address whether the differential trends across states are specific to firearm homicides or whether they reflect trends in lethal interpersonal violence more broadly. Specifically, we reran our primarily analysis including an additional covariate to control for differences across strata and time in non-firearm homicide rates. We identified non-firearm homicide rates from the National Vital Statistics System (NVSS) microdata using the following ICD-10 codes: U01(.0-.3,.5-.9), U02, X85-X92, X96-Y09, Y87.1. Death counts were converted to per capita rates using population data from SEER, and then Laplace-smoothed with add 0.05 smoothing. Finally, the smoothed rate was square-root-transformed. The decision to use a square-root transformation was determined by comparing model fit statistics across fixed-effect versions of our primary model using several different transformations (e.g., log-transformed, different power transformations). Including the non-firearm homicide rate as a control variable in the model was done to help ensure that we were documenting differences across demographic and geographic groups that are specific to firearm homicide. Results from this sensitivity analysis were highly similar to our primary findings, with the random intercepts across models correlated 0.995 and the random slopes correlated 0.574.

Correlation of 2014 rates and annual trend from 2014 to 2019

The state relative rates in 2014 (Figure 1, Panel A) and state relative annual trends from 2014 to 2019 (Figure 1, Panel B) are positively correlated across states (r=0.22). This positive correlation contrasts with what one would typically expect to observe between a baseline rate and subsequent change in rate due to, for example, regression to the mean (which would produce a negative correlation). Figure S3 plots each state's relative rate in 2014 against its relative annual trend, as well as the linear fit between the two measures.

Supplementary Figures

Figure S1a. Firearm and Non-Firearm Homicide Rates in the United States, 1979-2019

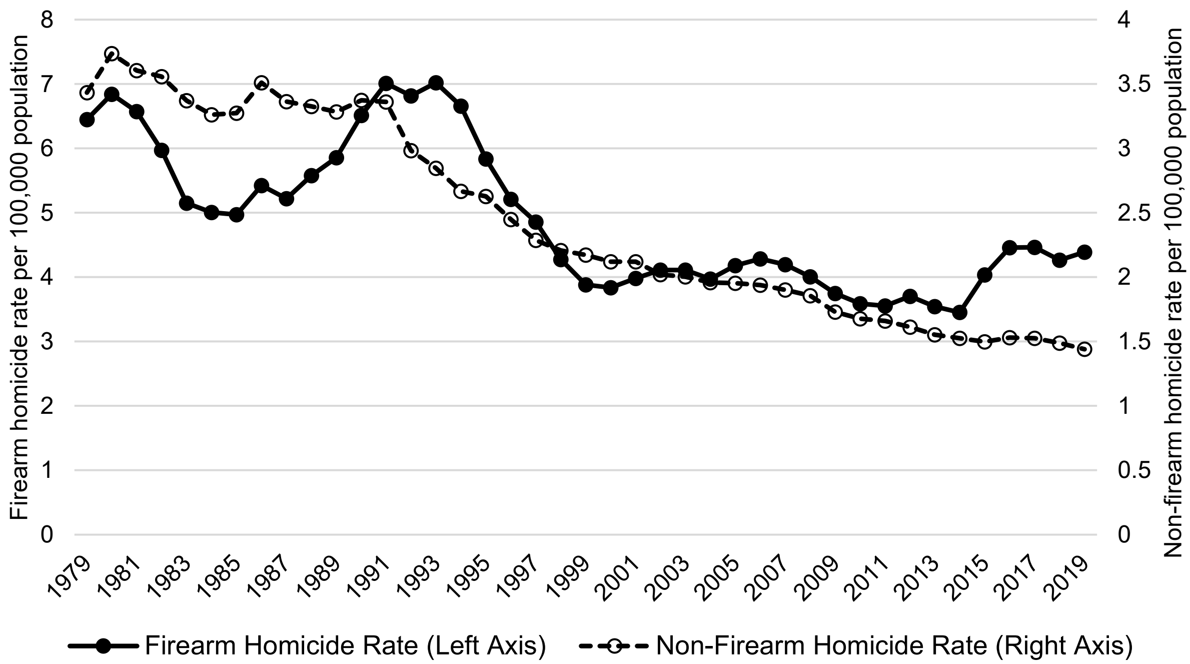
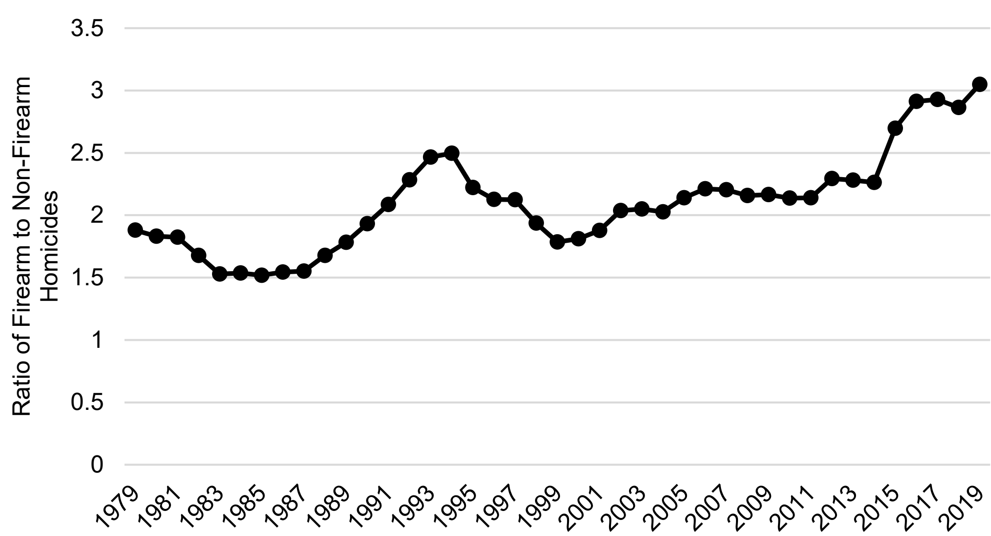
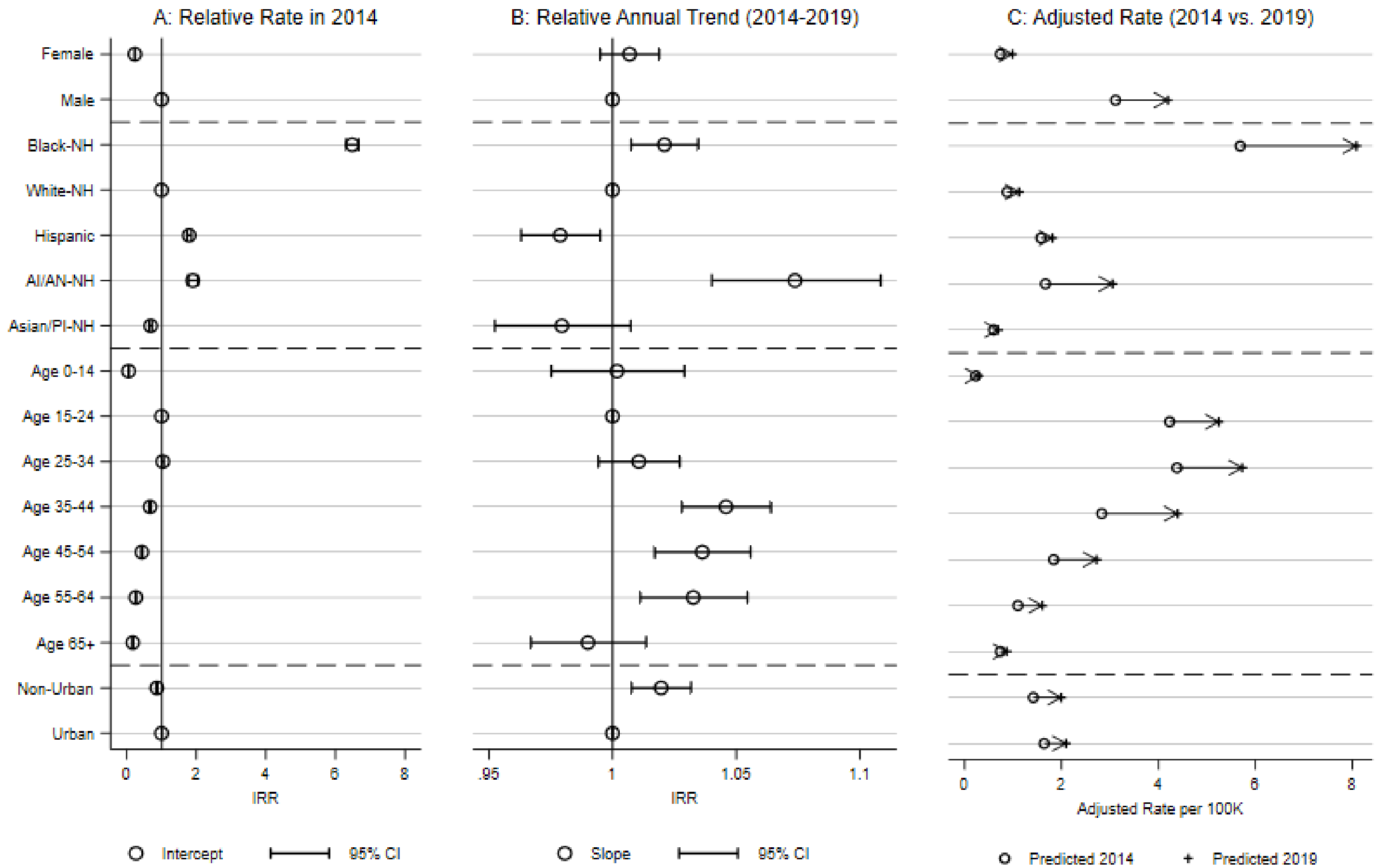


Figure S1b. Ratio of Firearm to Non-Firearm Homicides in the United States, 1979-2019



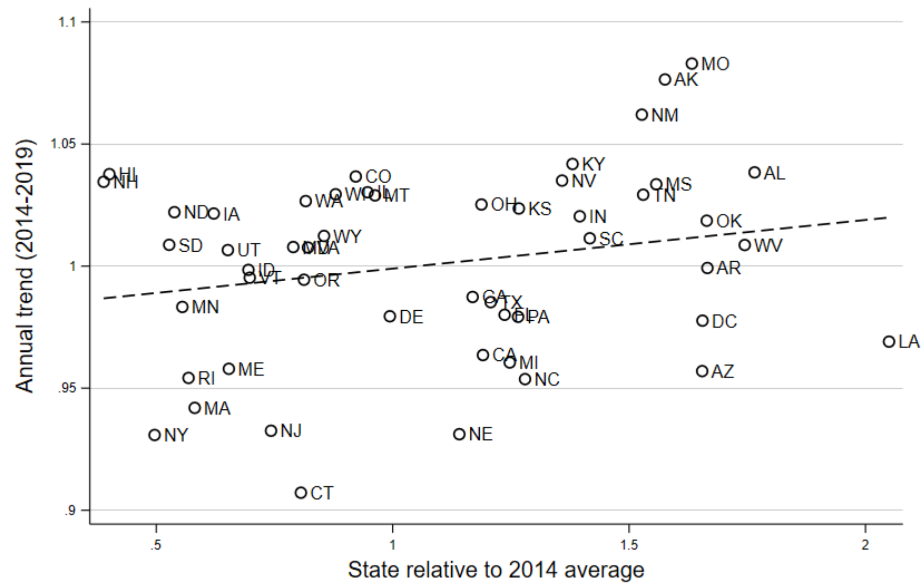
NOTES: Data from CDC WONDER. Excludes 2,915 non-firearm homicide deaths coded as U01.1 (Terrorism involving destruction of aircraft) in September 2001.

Figure S2. Adjusted incidence rate ratios (IRRs) and adjusted rate estimates, by demographic characteristic and urbanicity



NOTES: Panel A presents adjusted IRRs, and 95% confidence intervals (CIs), representing a given demographic group's rate of firearm homicide relative to the reference group (e.g., the IRR for female represents the relative firearm homicide rate for females relative to males). Panel B presents adjusted IRRs and 95% CIs for the interaction of the demographic effects with the spline for 2014 to 2019, such that IRRs represent annual trends relative to the national trend for the reference group (white, non-Hispanic males aged 15 to 24 in urban counties). Panel C presents model-based predicted firearm homicide rates for 2014 and 2019 for each characteristic, holding all other characteristics at their mean values, but allowing for national trends.

Figure S3. Comparison of State Relative Rates in 2014 with State Relative Annual Trends from 2014 to 2019



NOTES: Plot of the state relative rates in 2014 (Figure 1, Panel A) versus the state relative annual trends from 2014 to 2019 (Figure 1, Panel B). Dashed line represents the linear prediction of the annual trend from the state relative rate in 2014.

Supplementary Tables

Table S1. Regression results

	Incidence Rate Ratio (IRR)	
	Main Effect	Interacted Effect with 2014-2019 Trend
Sex (Ref: Male)		
Female	0.24	1.01
	[0.23, 0.24]	[0.99, 1.02]
Race/Ethnicity (Ref: White Non-Hispanic)		
Black Non-Hispanic	6.48	1.02
	[6.30, 6.66]	[1.01, 1.03]
Hispanic	1.80	0.98
	[1.74, 1.86]	[0.96, 1.00]
American Indian/Alaska-Native Non-Hispanic	1.90	1.07
	[1.77, 2.05]	[1.04, 1.11]
Asian/Pacific Islander Non-Hispanic	0.69	0.98
	[0.65, 0.73]	[0.95, 1.01]
Age Group (Ref: Age 15-24)		
Age 0-14	0.05	1.00
	[0.05, 0.06]	[0.97, 1.03]
Age 25-34	1.04	1.01
	[1.00, 1.07]	[0.99, 1.03]
Age 35-44	0.67	1.05
	[0.65, 0.69]	[1.03, 1.06]
Age 45-54	0.44	1.04
	[0.42, 0.45]	[1.02, 1.06]
Age 55-64	0.26	1.03
	[0.25, 0.27]	[1.01, 1.06]
Age 65+	0.18	0.99
	[0.17, 0.18]	[0.97, 1.01]
Urbanicity (Ref: Urban)		
Non-urban	0.86	1.02
	[0.84, 0.89]	[1.01, 1.03]
Time Trends		
Spline for 2006-2014	0.99	
	[0.99, 0.99]	
Spline for 2014-2019	1.02	
	[1.00, 1.04]	
Var(State random intercept)	0.184	
	[0.111, 0.257]	
Var(State random slope for 2014-2019)	0.002	
	[0.001, 0.003]	

NOTES: n = 86,240. 95% confidence intervals (CIs) in square brackets.

Supplementary Appendix References

1. National Center for Health Statistics. Detailed mortality – all counties (2006–2019), as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Hyattsville, MD: National Center for Health Statistics; 2020.
2. Regoeczi W, Banks D, Planty MG, Langton L, Annest JL, Warner M, Barnett-Ryan C. The nation's two measures of homicide. Washington, DC: Bureau of Justice Statistics; 2014.
3. National Center for Health Statistics. Technical appendix. Vital statistics of the United States: Mortality. Washington, DC. Published annually. Available from: https://www.cdc.gov/nchs/products/vsus/ta.htm#
4. Loftin C, McDowall D, Curtis K, Fetzer MD. The accuracy of Supplementary Homicide Report rates for large U.S. cities. Homicide Studies 2015;19(1):6-27.
5. Loftin C, McDowall D, Fetzer MD. A comparison of SHR and Vital Statistics homicide estimates for U.S. cities. Journal of Contemporary Criminal Justice;24(1):4-17.