ENVIRONMENTAL POLLUTION AND CRIME

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Before discussing the role of environmental pollution in the complex interactions of "Biology, Behavior, and the Criminal Law," it is useful to identify three common misperceptions concerning discussions of law and biology. First, "biology" is *not* identical with genetics. The life sciences study the development and evolution of organisms in their environments; hence, as the research reported below illustrates, this field often provides unique insights into the *environmental* factors in human behavior. Second, "biological" characteristics are not immutable. The life sciences are not deterministic, and as modern medicine proves daily, discovering the complex relationships between inherited, developmental, and environmental factors often greatly *increases* human control over outcomes. Finally, biological approaches to human behavior need not entail the abandonment of legal and moral responsibility, especially for criminal actions. As neuroscientists have shown, what one thinks can influence the function and even neurochemistry of the brain.[1]

It follows, as James Q. Wilson has eloquently argued in his recent Godkin Lectures at Harvard University, that judgment of a criminal's behavior in a court of law is and should remain sharply different from scientific explanations of that behavior.[2] Knowledge of the factors influencing behavior gives humans increased ability to control outcomes. Because life-styles and behavioral choices are essential factors in vulnerability to environmental toxins like those discussed in the following analysis, this approach effectively *enhances* the legal and moral responsibility of the individual.[3] In legal terms,

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1. *See generally* PAUL M. CHURCHLAND, THE ENGINE OF REASON, THE SEAT OF THE SOUL (1995) (stating that the central nervous system is a recursive, massively parallel information processing system in which feedforward as well as feedback neural networks constantly reconstruct sensory input and memory; as a result, moral and law abiding behavior needs to be seen as a *skill*, not as the deduction of a specific case from a general rule).

2. *See* JAMES Q. WILSON, MORAL JUDGMENT 7 (1997) (asserting that the tendency to allow social scientific explanations of behavior to generate exculpatory evidence is undermining our criminal law, with serious implications for the public support of our legal system).

3. *See* Roger D. Masters, *Conclusions for Public Policy*, *in* THE NEUROTRANSMITTER REVOLUTION: SEROTONIN, SOCIAL BEHAVIOR AND THE LAW 227-42 (Roger D. Masters & Michael T. McQuire eds., 1993) (surveying the role of serotonin and other neurotransmitters in modulating human social behavior; and arguing that these biological explanations need not, and should not, have an

nothing in the biological study of human behavior justifies the abandonment of the traditional concept of mens rea.

I. THE BIOLOGY OF VIOLENCE

Although sociologists and criminologists often debate the origins and character of crime, from a biological perspective individual acts of violent behavior among humans are abnormal (in the sense of rare). Among other primates, aggressive or threatening behavior is statistically infrequent. For example, in twenty-five years of observing chimpanzees, Jane Goodall noted overtly aggressive acts in only 1.6% of observation hours among males and a mere 0.6% for females; more importantly, chimpanzee threat displays usually end without physical violence.[4] For other primates as well, while threats are part of the normal primate behavioral repertoire, they are usually inhibited and do not result in wounds or physical harm.[5]

It should therefore not be surprising that humans typically respond to a broad diversity of social situations, including instances when others show signs of threat or anger, without engaging in violent behavior. Although criminal violence is abnormal in this purely statistical sense, feelings of anger and hostility are part of our innate emotional and behavioral repertoire. Thus, from a biological perspective, violent crime appears to reflect the failure of normal systems of inhibition.[6]

The strongest evidence for this view comes from contemporary neuroscience. As David Goldman explained earlier in this symposium, mammalian social behavior is modulated in part by a complex system of neurotransmitters which can regulate the response strength of excitatory or inhibitory circuits in the brain. Serotonin, one of the best known of these regulatory chemicals—due to the popularity of Prozac, which increases serotonin's functional activity—has frequently been shown to play an inhibitory role in humans, as well as other mammals. Consistent with the view that violence often requires a failure of normal inhibitory mechanisms, deficits in serotonin have been associated with more frequent violent behavior not only in humans, but in nonhuman primates.

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exculpatory effect in criminal law; on the contrary, knowledge of these explanations should make possible enhanced responsibility for violations of social norms and laws) [hereinafter THE NEUROTRANSMITTER REVOLUTION].

4. *See* JANE GOODALL, THE CHIMPANZEES OF GOMBE 314 (1986) (surveying 25 years of observation of chimpanzee social behavior at Gombe).

5. *See generally* FRANS DE WAAL, GOOD NATURED (1996) (discussing the role of social cooperation as well as competition among chimpanzees and other primates).

6. *See generally* KONRAD LORENZ, ON AGGRESSION (1966) (emphasizing the natural origins of threat behavior and the essential role of inhibition in animal and human social behavior).

The mechanisms associated with this process are the result of hominid evolution as a group-living primate, interacting with others in face-to-face groups with normally less than two hundred members. Like other primates, we react instantaneously to facial displays and other nonverbal cues of the emotions and likely behavior of others. Among these displays are cues of anger, threat, and possible attack which humans from virtually every known culture distinguish accurately.

We perceive anger, and instantaneously respond emotionally to it; but then monitor our own feelings in the light of social norms and cultural expectations. If a parent sees a child about to hit another child, for example, it is not difficult to recognize the threat and intervene before the actual hitting takes place. These reactions are part of a broader system of emotional expression and social display behavior that is universal and innate to our species, but shaped and modified in each culture.[7]

For over fifteen years, I have been studying the role of this system of nonverbal displays in voter responses to political leaders, which provides an excellent example of "normal" or routine human social behavior toward a known person. Perceptions of the behavior of others are in fact filtered through many individual traits, including personality (some individuals are fearful and highly sensitive to threat, others relatively insensitive), attitudes toward the individual observed, and cultural expectations. Whatever these perceptions, experiments confirm that feelings elicited by the behavior of others are organized into two neuroanatomically and functionally distinct systems, usually called positive (hedonic) and negative (agonic or competitive). As a result, the experience of seeing another person's facial displays of emotion unconsciously activates the facial muscles underlying our own displays of emotion and triggers congruent feelings of positive and negative emotion.[8]

Because the neuroanatomical system underlying these responses is innately wired into the brain, we constantly monitor the intentions of others and respond emotionally and cognitively to them. In this process, both the positive (cooperative) and negative (competitive) circuits function simultaneously, so that our conscious responses reflect the net outcome of diverse cues and feelings. Contrary to the views of theorists in the tradition

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7. *See generally* ROGER D. MASTERS, THE NATURE OF POLITICS (1989) (noting the expressive and social functions of human facial displays and their relation to both innate or natural and cultural or cognitive elements); A. Michael Warnecke et al., *The Roots of Nationalism: Nonverbal Behavior and Xenophobia*, 13 ETHOLOGY & SOCIOBIOLOGY 267-82 (1992) (presenting experimental data of differences in responses to nonverbal cues of foreigners).

8. *See generally* ROGER D. MASTERS, BEYOND RELATIVISM (1993) (explaining that nonverbal displays of emotion can be understood as "innate ideas," communicating information about the social behavior and feelings of others that plays a necessary and ubiquitous role in normal social life).

of Rousseau, therefore, aggressive or competitive emotional responses are as natural to humans as positive or bonding responses.

Human morality and obedience to law are based in part on this complex system of emotions.[9] Positive emotional feelings are associated not only with physical pleasures but with events and ideas that confirm firmly held beliefs in expected social behavior. When one sees people doing proper things, it makes one feel good. When one sees them violating the rules, it makes one angry. While these emotional responses are triggered when our own interests are threatened, normally they are also aroused when, as bystanders, we see innocent people being harmed and social rules flouted.

These findings have a direct relevance to understanding human crime. It is not the case, as some have thought, that violence occurs because the criminal has imagined killing someone, whereas normal human beings never have such thoughts. Recent studies show that in a given year, as many as 70% of males and a majority of females have imagined in detail killing another person.[10] While cultural and social circumstances can increase or decrease the extent of imagined aggressiveness toward those who act unfairly toward us or thwart our desires, we all have feelings of aggression that we normally inhibit. And although the fear of punishment is involved in the capacity to inhibit aggressive impulses, so too is the anticipated reward of conforming to legitimate and expected social norms. Humans are, by nature, social animals.

From this perspective, violent offenders seem to have some systematic deficit in the way the central nervous system processes the displays of social and emotional behavior of others. Although the failure to inhibit anger and threatening feelings may be a common factor in violent crime, individual offenders almost certainly differ in the mechanisms that weaken this capacity to inhibit aggressive behavior. For a small proportion of the population, known as "primary psychopaths" (and often associated with incorrigible repeat offenders), the basic link between the perception or expression of social displays and emotions does not function normally. In these individuals, symbolized by Kevin Bacon's violent offender character in the film *The River Wild*,[11] feelings of bonding and sympathy are rarely, if ever, aroused, and nonverbal behavior is used, under cognitive control, for "cold-blooded" selfishness.[12] Most criminals, however, probably are capable of normal

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9. *See generally* MARGARET GRUTER, LAW AND THE MIND (1993) (asserting that understanding the legal process requires an understanding of the evolutionary analysis of the way humans behave, including emotional and nonverbal social factors long ignored by many legal theorists).

10. *See* Douglas T. Kenrick & Virgil Sheets, *Homicidal Fantasies*, 14 ETHOLOGY & SOCIOBIOLOGY 231 (1993).

11. THE RIVER WILD (Universal 1994).

12. *See generally* ROBERT HARE, WITHOUT CONSCIENCE (1993) (noting that the roots of

emotional responses, but have deficits in the positive emotional responses to bonding and normal law-abiding behavior, or in the inhibitory circuits that prevent angry emotions from erupting into physical violence, or both.

Recently, this view has been confirmed by an experimental study of Vermont prison inmates conducted by a former student of mine, Baldwin Way, now in the Department of Neuroscience at UCLA.[13] Preliminary data from this study provides evidence that violent offenders differ from non-violent criminals as well as law-abiding citizens used as controls, in the responses to the facial displays and nonverbal cues underlying normal social behavior.

In these experiments, viewers were asked to describe the facial display behavior of known leaders in a video excerpt shown without the sound, using separate rating scales for how happy, comforting, angry, and fearful the leader was. Over the previous fifteen years of experiments, we have found that these ratings provide an accurate assessment of the facial displays of others (as is confirmed by scientific ratings and cross-cultural studies of the same behavior). When the research was extended to prison inmates, we found no statistically significant differences between the "net description" by violent offenders, nonviolent prison inmates, and controls who had been subjects in similar experiments in a university setting.[14] When seeing a neutral image of a leader, people who commit violent acts do not seem to *see* more or less aggressiveness than normal people.

In over fifteen years of experiments, such descriptive scores after watching a leader have been strongly correlated with viewers' emotional responses during the excerpt, measured as the "net warmth" of positive emotions (happiness and comfort) minus the negative feelings (anger and fear). However, when the violent offenders looked at videotapes of the President's neutral displays, they did not report feeling the level of positive emotion that would be predicted from their perceptions.[15] At this level, there was a statistically significant difference between violent offenders, and either nonviolent prison inmates or law-abiding controls.

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behavioral characteristics of "primary psychopaths" lie in abnormal brain processing of emotion).

13. We thank John Gorzyck, Commissioner of Corrections, and John Perry, Director of Research for the Department of Corrections of the State of Vermont, for their assistance in making possible this study, which was funded by the Rockefeller Center for the Social Sciences at Dartmouth College.

14. *See infra* Figure 1. The "net description" is the overall rating of positive cues of happiness and comfort, minus negative cues of anger and fear. For the methods in this experiment, see Baldwin M. Way & Roger D. Masters, *Political Attitudes: Interactions of Cognition and Affect*, 10 MOTIVATION & EMOTION 219-36 (1996) (examining the effects of subliminal cues of emotion on the perception, emotional response, and attitudes to President Clinton). For the prison study, we present data for all experimental conditions combined.

15. *See infra* Figure 2.

Violent criminals do not seem to experience the normal emotions that lead to bonding with significant social others. Because this lack of positive feeling toward an authority figure was not observed among the nonviolent offenders in our prison sample, we may have discovered a common trait associated with the weakness of inhibiting aggressive behavior that I have suggested is a proximate mechanism in violent crime.

There are doubtless many possible reasons for an individual to exhibit abnormal emotional responses, poor social bonding, and weak inhibition of aggressive impulses. Developmental experiences, brain damage due to child abuse or disease, and socioeconomic deprivation are among the many "risk factors" that might combine to prevent the typical emotional responses to others. Our experimental data shows, however, that when the same violent offenders see an aggressive excerpt of the President, their positive emotional responses are congruent with the level of their descriptions of the excerpt. Hence the failure to bond to a neutral image of the national leader does not seem to be due to the total absence of emotional responsiveness. The neurons of violent offenders seem to be connected, but there is something different about the functional way that their brains operate.

Such findings are consistent with the view that there may be a "final common pathway" of abnormal social disinhibition that characterizes the diverse etiologies leading to criminal violence. Whatever the initial reasons for becoming a violent criminal, these risk factors must impinge on one of the many functional processes by which the human brain perceives and responds to social situations.

II. ENVIRONMENTAL FACTORS IN CRIMINAL VIOLENCE

According to conventional approaches, criminal behavior is a function of the conscious thoughts and intentions of the criminal in response to the social environment. Critics often jump to the conclusion that a biological perspective implies a reduction of these conscious choices to some form of molecular determinism within the brain. This need not follow, however. To the contrary, the complex causal pathways merely presume that the effects of either individual choices or social environments must impinge on the central nervous system if they are to explain the eruption of violent behavior.

It is easy to give a concrete illustration of the problem of analyzing the environmental factors in criminal violence. According to one widely shared view, television violence is one of the main explanations for the high rates of violent crime in the United States. While exposure to television violence might be a risk factor for crime, the usual argument meets two powerful objections. First, millions of Americans see violence nightly on television:

why do only some individuals commit such acts?[16] Second, rates of violent crime vary sharply from one place in the United States to another.[17] Since television violence is largely a constant, if it causes crime, why do individuals and environments differ so greatly in response to it?

Much the same challenge can be addressed to many other conventional explanations for crime. For example, poverty and unemployment are often said to be major reasons for criminal behavior. Yet not all poor or unemployed people are criminals, and some relatively poor counties and regions have remarkably low crime rates. When sociologists insist on a radical dichotomy between "nature" and "nurture," they often attribute behavior to environmental factors that are too broadly defined to account for the actual phenomena observed.

Paradoxically, however, these same risk factors may indeed play an important role for individuals with abnormalities in brain function that undermine normal inhibitory mechanisms. In particular, biochemical imbalances may be associated with many of the factors that have been widely associated with criminal violence, permitting us to see how *combinations* of these risk factors can trigger violence even when the same individual or social phenomena do not lead to crime.

For example, a very large proportion of violent offenders were under the influence of alcohol at the time of their criminal behavior. Although the disinhibitory effects of alcohol are well known to anyone who has relaxed during a cocktail hour, most of those who consume alcoholic beverages are not violent. Low levels of serotonin have also been associated with weakened inhibition, but the effects of this chemical condition range from psychological depression or obsessive-compulsive disorder, to an increased vulnerability to accident and suicide, as well as to increased frequencies of aggressive behavior.[18] As Markku Linnoila and his colleagues at the National Institute of Alcoholism and Alcohol Abuse have shown, however, the *combination* of alcoholism, low serotoninergic function, and a third biochemical condition, low glucose uptake, are highly predictive of impulsive violence or arson.[19]

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16. In 1991, the average rate for all violent crimes—homicide, aggravated assault, sexual assault, and armed robbery—in a county in the United States was 320 per 100,000 persons. Search of USA COUNTIES ON CD-ROM, based on STATE AND METROPOLITAN AREA DATA BOOK, 1982, 1986, & 1991 (Washington D.C.: U.S. Census Bureau, 1994).

17. In some counties, the violent crime rate is under 200 per 100,000 persons, whereas in urban centers like Baltimore the rate can be over ten times higher. *See id.*

18. *See generally* PETER KRAMER, LISTENING TO PROZAC (1993) (describing clinical evidence of the effects—sometimes remarkable—of psychoactive drugs like Prozac in treating a wide variety of psychiatric symptoms and personal problems). *See also* THE NEUROTRANSMITTER REVOLUTION, *supra* note 3.

19. *See* Markku Linnoila et al., *Serotonin and Violent Behavior*, *in* THE NEUROTRANSMITTER REVOLUTION, *supra* note 3, at 61 (explaining that biochemical and behavioral markers provide highly

Other factors usually traced to the social or cultural environment also have their effects only insofar as they are mediated through changes in normal brain function. For example, social stress is an independent factor in regulating neurotransmitters. Individuals under prolonged social stress reduce the production of a number of neurotransmitters including serotonin and dopamine. Their immune systems also function less effectively, increasing the frequency of disease. While many non-scientists think of social stress as an environmental factor, its effects are also felt at the level of brain biochemistry and neuronal function.

Indeed, this probably explains why hard drug use spans diverse social groups—including not only ghetto youths in disintegrating socio-cultural environments, but also high status, highly-stressed professionals in the business and entertainment worlds. Cocaine, for example, is a nonselective dopamine re-uptake inhibitor. Like those who take Prozac (a selective serotonin re-uptake inhibitor), therefore, illicit drug users may be attempting to normalize brain chemistry imbalanced for diverse reasons often including social stress.

Similarly, social status changes brain chemistry. When a low status monkey (or human) gains dominance, the perception of submissive behavior in others leads to an increase in serotonin levels. When a teacher stands in front of a class, or a judge enters a courtroom, the perception of subordination has the same effect as taking Prozac. Because uncertain social status or isolation lowers serotoninergic levels, it is not hard to see how gang membership can entail rewards at the biochemical as well as the conscious and behavioral levels.[20]

Among the many factors that can impinge on the neurochemical or functional efficacy of the human brain, many arise from the combined effects of dietary insufficiencies, substance abuse, and environmental pollution. At the individual level, violent offenders are more likely to have absorbed toxic metals like lead or cadmium and manganese in their blood and brain. In seven of seven studies of toxic elements in the head hair of prison inmates, and as Professor Deborah Denno[21] explained in this symposium, the absorption of lead in blood, and the presence of anemia (which facilitates the uptake of lead in the brain) are two of the most accurate predictors of the likelihood of seven-

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accurate *prediction* for recidivism for impulsive violence—violent crimes in which the name of the victim is unknown to the attacker—or arson; testing serotonin levels in blood and glucose uptake permits a discriminant analysis in which there are less than 10% of either false positives or false negatives when predicting, at sentencing for a first offense, a repeat crime after release from prison).

20. *See* Michael Raleigh & Michael T. McGuire, *Serotonin, Aggression, and Violence in Vervet Monkeys*, *in* THE NEUROTRANSMITTER REVOLUTION, *supra* note 3, at 129.

21. *See* Deborah W. Denno, *Gender Differences in Biological and Sociological Predictors of Crimes*, 22 VT. L. REV. 305 (1997).

year-old inner city residents becoming juvenile delinquents or adult violent criminals.

Could it be that environmental pollution is among the environmental risk factors for violent crime? This question, which makes sense when criminal violence is analyzed from a biological perspective, is rarely addressed by traditional criminologists. The hypothesis explored below shows, furthermore, that far from oversimplifying the causes of crime, the search for intervening biological mechanisms suggests additional environmental risk factors associated with violence that have unfortunately been ignored by criminologists. Among these, I will argue, absorption of neurotoxic metals is perhaps the most important missing link in our theories of violence.

III. NEUROTOXICITY AND VIOLENCE

Some heavy metals, such as lead, cadmium, manganese, and mercury, are highly neurotoxic. If these elements cross the blood-brain barrier and are absorbed in neurons, crucial changes in brain structure and function result. In particular, toxins like lead and manganese reduce the functional level of essential neurotransmitters, including serotonin, dopamine, acetylcholine, and gamma aminobutyric acid (GABA). Normally, humans excrete these toxins without absorbing them in the brain. When vital elements such as calcium, iron, or zinc are missing from the diet, however, the neurotoxic metals—which often have a similar electric charge—are absorbed in their place. Exposure to toxic elements, poor diet, and substance abuse therefore have interacting effects on the brain function and social behavior.

> Changed brain chemistry can alter behaviour, and changed behaviour can alter brain chemistry: the interaction is two way. It therefore follows that behaviour, cognition, social interactions, and other expressions of brain function are subject not only to the social environment but also to certain aspects of the chemical environment. The relevant chemical factors include (a) neurotoxic pollutants in general, of which lead is evidently now the most serious in its impact, (b) certain common nutrient deficiencies, particularly of zinc, and (c) neurotoxins of voluntary abuse, of which ethanol is still probably producing the most widespread social damage.[22]

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22. Derek Bryce-Smith, *Environmental Chemical Influences on Behaviour and Mentation*, 15 CHEM. SOC. REV. 122 (1986) (citations omitted).

This approach is especially relevant to violent crime because neurotoxic elements can alter neurotransmitter function by disinhibiting aggressive impulses under stress. In addition to lead, manganese is a neurotoxic metal that has been associated with violence. Among the dietary deficiencies, increasing neuronal uptake of toxic metals are deficits in calcium and other essential vitamins, as well as zinc. Since there are geographic variations in the incidence of pollution, alcoholism, and populations with dietary deficiencies, the neurotoxicity hypothesis can be used to predict differences in rates of violence, using county-level data that are likely to reflect the influence of environmental pollution. Data testing this prediction shows that exposures to lead and manganese, especially when combined with alcoholism, are highly correlated with increased frequency of violent crime.

A. Lead Toxicity

Behavioral and cognitive deficits caused by lead, noted in antiquity by Hippocrates, have been the subject of widespread scientific analysis.[23] Although legislation prohibiting lead in gasoline additives and paint reduced lead levels in blood by seventy-eight percent between 1976-1978 and 1988-1991,[24] toxic release of lead and lead compounds remains a serious problem due to aging water systems and industrial pollution. Exposure to subclinical doses of this neurotoxic metal can be a major hazard for three principal reasons: (1) children absorb up to fifty percent of the lead they ingest, compared to eight percent for adults; (2) prolonged exposure to even very low doses of lead can cause neuronal damage during early development, resulting in lasting cognitive and behavioral deficits; and (3) the highest levels of lead uptake are reported for the population groups most likely to commit violent crimes. Because the consequences of exposure depend on lifestyle factors such as alcoholic consumption, smoking, and diet, moreover, averages for a population will tend to mask the risks arising from combinations of co-factors.

Prolonged exposure to low levels of lead can influence dopaminergic, cholinergic, and glutamatergic neurotransmitter functioning, producing learning deficits that include impairment of passive avoidance learning—the capacity to be deterred by future punishment. Attention Deficit Disorder (ADD) and Attention Deficit Hyperactivity Disorder (ADHD), conditions

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23. *See generally* HUMAN LEAD EXPOSURE (Herbert L. Needleman ed., 1989) (offering an excellent survey of the nature and effects of lead toxicity). For more extensive documentation, see ROGER D. MASTERS ET AL., *Environmental Pollution, Neurotoxicity, and Criminal Violence*, in ASPECTS OF ENVIRONMENTAL TOXICOLOGY 13-48 (J. Rose ed., forthcoming 1998) (reviewing evidence for the neurotoxicology hypothesis and supporting data).

24. *See* J. Pirkle et al., *The Decline in Blood Lead Levels in the United States*, 272 J. AMER. MED. ASSN. 284 (1993).

frequently associated with juvenile delinquency, have also been traced to prolonged exposure to lead. Analyses of the head hair of violent offenders often show significantly higher levels of lead, sometimes combined with higher levels of another toxic metal such as cadmium, when compared to nonviolent controls. That subclinical plumbism has behavioral effects is, moreover, confirmed by measures of educational success, such as the correlation between lead levels in tooth enamel and lowered IQ scores.[25]

B. Manganese Toxicity

Manganese has also been associated with subclinical behavioral disturbances due to its effects on neurotransmitter function.[26] Although industrial manganism can be traced to direct exposure to large quantities of manganese dioxide or manganese nitrate, chronic exposure to low levels of manganese is probably more relevant to loss of impulse control and outbursts of violent behavior, especially under stress.

Exposure to manganese lowers levels of serotonin in the brain, while paradoxically increasing serotonin levels in blood and body tissue; manganese also degrades dopamine and reduces levels of essential minerals in brain cells. While the mechanism of these effects is not clearly understood, some of these effects may be due to altered levels of monoamine oxidase (MAOA). However produced, low levels of serotonin in the brain are associated with mood disturbances, poor impulse control, and increases in aggressive behavior—effects that have increasingly been treated with Prozac and other psychotrophic medications that enhance serotoninergic function.

Vitamin and mineral deficiencies play a central role in manganese uptake. In laboratory studies, where environmental exposure alone does not lead to toxicity, animals with deficits in calcium intake show significant manganese retention. Other aspects of diet also influence the absorption of manganese. For example, laboratory animals raised on infant formula have cellular retention of manganese that is five times greater than controls raised on human mother's milk. The combination of calcium insufficiency and manganese toxicity could therefore be described to the general public as "reverse Prozac."

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25. *See* Herbert L. Needleman et al., *The Long-Term Effects of Exposure to Low Doses of Lead in Childhood*, 322 NEW ENG. J. MED. 83, 83-88 (1990).

26. *See* John Donaldson, *The Physiopathologic Significance of Manganese in Brain: Its Relation to Schizophrenia and Neurodegenerative Disorders*, 8 NEUROTOXICOLOGY 451, 456-62 (1987) (listing technical evidence of neurotoxic effects of manganese). For fuller documentation, see Way & Masters, *supra* note 14.

C. Brain Biochemistry and Synergy

Other elements have effects on brain biochemistry that can either increase or reduce probabilities of violent behavior. Lead and cadmium apparently interact, with significantly higher levels of cadmium found in samples of those violent offenders with higher lead in head hair analyses. Further, relatively low levels of zinc have been associated with increased lead uptake. Conversely, lithium reduces the levels of manganese and other toxic metals in the brain, and is lower in hair samples of violent offenders than in hair samples from controls. At the population level, homicide rates in Texas were inversely related to levels of lithium in the water supply. Other studies of violent or violence-prone individuals have shown abnormal levels or ratios of a variety of elements or toxic metals.[27]

Ethanol in alcoholic beverages may be the most important substance that interacts with toxic metals. In laboratory animals, the effects of a toxic element (cadmium) and of ethanol were "significantly altered," especially because "animals exposed to alcohol alone have a significantly greater accumulation of cadmium in liver and intestine and a tendency for greater accumulation in other organs as compared to their normal counterparts. . . . This . . . is likely due to the increased permeability of membrane in the presence of ethanol."[28] In humans, ethanol interacts with the physiological effects of lead on blood pressure and other physiological processes. Alcohol reduces behavioral inhibition by enhancing the effects of other toxins that reduce the levels of functional activity of inhibitory neurotransmitters (as manganese does for serotonin) or damage inhibitory neuronal structures (as lead does for interneurons). Not surprisingly, consumption of alcohol is associated with a very high proportion of violent crimes.[29]

While suggestive, these studies do not provide convincing evidence that the synergy between manganese, lead, and other substances contributes to differential rates of criminal behavior. The data implicating neurotoxicity at the individual level can, however, be verified by contrasting rates of violent crime in geographical areas with and without releases of toxic metals as well as with lower or higher rates of alcoholism. To be sure, there are many other possible risk factors explaining violence. Moreover, Environmental

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27. *See generally* Gerhard N. Schrauzer et al., *Lithium in Scalp Hair of Adults, Students, and Violent Criminals*, 34 BIOLOGICAL TRACE ELEMENT RES. 161-76 (1992) (noting that individuals with higher lithium levels have lower levels of criminal behavior).

28. Geeta Sharma et al., *Effect of Ethanol on Cadmium Uptake and Metabolism of Zinc and Copper in Rats Exposed to Cadmium*, 121 J. NUTRITION 87, 90 (1991).

29. For a review of the literature, see generally Roger D. Masters et al., *Brain Biochemistry and Social Status: The Neurotoxicity Hypothesis*, *in* INTELLIGENCE, POLITICAL INEQUALITY, AND PUBLIC POLICY 141 (Elliott White ed., 1997).

Protection Agency (EPA) reports of toxic release do not report all sources of pollution. But, as Felton Earls puts it, "an adequate theory must explain why rates of violence differ by age, gender, and size of community, and whether it is environmental conditions that cause individuals to behave violently (social causation), or whether persons prone to behave violently create environments characterized by high rates of violence (social selection)."[30]

IV. EMPIRICAL EVIDENCE LINKING POLLUTION AND CRIME

We have tested the hypothesis that neurotoxicity is among the factors related to violent crime by using ecological data on the distribution of environmental pollutants to predict the rates of criminal violence. The EPA's Toxic Release Inventory (TRI) for lead and manganese was correlated with FBI crime reports from 1,165 counties in 16 states with a total population of over 130 million.[31] This approach cannot measure the effect of the individual's childhood environment. However, the realities of economic stratification suggest that the county of current residence has a high probability of being ecologically similar to the childhood environment. If so, for most of the population, present exposure to toxic metals should also be a rough measure of environmental exposure during development.

A. The Effects of Lead and Manganese

The distribution of manganese and lead pollution is highly skewed: over seventy-five percent of counties have no release of either manganese and its compounds, or lead and its compounds recorded in the TRI. Correlations between pollution from these two metals and several behavioral outcomes—crime, alcoholism and dropping out of high school—are significant but non-linear. Because toxicity occurs at levels of micrograms per gram, even an average level of toxic release (2,540.9 pounds/year of manganese and 4,101.5 pounds/year of lead) could adversely effect a substantial population.

When counties are dichotomized for the presence or absence of lead and manganese toxic releases, the two-way analysis of variance (ANOVA) shows that pollution from each of these neurotoxic metals is significantly associated with increased rates of violent crime: in the 166 counties with pollution from both sources, rates of violent offenses were 520 per 100,000, as compared to

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30. Felton J. Earls, *Violence and Today's Youth*, 4 FUTURE OF CHILDREN 4, 11 (1994).

31. The states were: Alabama, Arizona, California, Florida, Georgia, Illinois, Massachusetts, Mississippi, Minnesota, New Hampshire, New York, Pennsylvania, Texas, Vermont, Washington, and Wisconsin. Search of USA COUNTIES ON CD-ROM, *supra* note 16.

the sample average of 350 per 100,000. The effects are highly significant for both manganese toxic releases ($p = .0039$, $F1,1137 = 8.36$) and lead toxic releases ($p = .0001$, $F1,1137 = 31.22$), with no statistically significant interaction between them.[32]

These effects are confirmed by focusing on counties whose rates of violence are either well above average or unusually low.[33] Among the 310 counties with relatively high rates of the FBI's four categories of violent crime (more than 400/100,000 per year), releases of both manganese and lead are significantly higher than in the 255 low-crime counties with rates under 100/100,000 per year.[34] Other statistical measures, such as analysis of those counties in the top decile of toxic releases of either lead or manganese, and the independent effects of toxic releases of the element of each metal and its compounds, are consistent with the hypothesis.

These correlations between environmental pollution and crime do not seem to be statistical artifacts. Multiple regression models, predicting the level of pollution in each county on the basis of socioeconomic and ethnic variables—e.g., population composition, per capita income, unemployment rates—explain less than five percent of the variance for either lead or manganese releases. Although few rural counties (those with population densities below twenty per square mile) have reports of either lead or manganese releases, the geographic distribution of pollution from these sources seems to be a distinct variable which criminologists have not adequately studied.

B. The Effects of Alcoholism

Because consumption of alcohol is frequently associated with violence, if alterations in brain chemistry increase the risk of violent aggression, one might expect interactions at the population level among environmental pollution, rates of alcoholism, and violent behavior. To test this extension of the hypothesis, deaths from all forms of alcoholism were dichotomized at the sample average and used as a measure of the varying degree of alcohol usage in each county. The three way ANOVA—presented as Figure 5, *infra*—shows that when this factor is combined with exposure to pollution from lead and manganese, all three factors are highly significant (lead $p = .0001$, $F1,1111 = 48.114$; manganese $p = .0001$, $F1,1111 = 16.836$; alcoholism $p = .0001$, $F1,1111 = 70.217$), with significant interactions between

32. *See infra* Figure 3.
33. *See infra* Figure 4.
34. Search of USA COUNTIES ON CD-ROM, *supra* note 16.

manganese toxic release and alcoholism ($p = .0001$, $F1,1111 = 15.512$) and between lead toxic release and alcoholism ($p = .0347$, $F1,1111 = 4.473$).

Students of human behavior have rarely explored such complex interactions or synergies between environmental toxins and consumption. In laboratory experiments, as noted above, exposure to a toxic metal like manganese has effects that vary depending on diet. The effects of lead, manganese, and alcohol seem to have a similar synergy. In counties with no reported releases of lead or manganese and below average rates of alcoholism, rates of violent crime are below average (250/100,000). In contrast, the 57 counties of our sample with toxic releases from both metals and above average alcoholism rates have three times as much violent crime, with a county rate of 790/100,000. Although epidemiologists are increasingly aware of the importance of such synergies or interactions, most conventional models in criminology have looked at each variable independently.

C. The Effects of Other Risk Factors

To ascertain how these effects might relate to other risk factors associated with violence, a multiple regression was computed using twenty-two socioeconomic and demographic variables to predict rates of violent crime. Although such multiple-regression equations are notoriously sensitive to the variables included and the linearity of effects, these results are consistent with the hypothesis that both alcoholism and dietary insufficiencies are risk factors that interact with environmental pollution. Since about three-fourths of counties studied had no releases of lead or of manganese and the effects of pollution are nonlinear, it is not surprising that levels of toxic releases are not independent predictors of violent crime in the regression model.[35] It is interesting, however, that two of the variables with the highest standardized coefficients are alcoholism, which is associated with *higher* crime rates, and per capita expenditure on welfare, which is associated with *lower* rates of violent crime (perhaps because of the contribution of food stamps to improved diet among the poor). Independent contributions of white, black, and hispanic poverty, controlling for rates of unemployment, urbanism, and the overall wealth of a county, also suggest that violent behavior is more likely for those with dietary insufficiencies in calcium and other essential

35. That this is an artifact of the size of the sample is confirmed by the comparable statistics from a global sample of 2899 counties from the 48 contiguous states, in which both multiple regression and structural co-variate analyses confirm the independent contribution of environmental neurotoxic releases as a risk factor in crime. *See* MASTERS ET AL., *supra* note 23, at 34, 36; *see also* Masters et al., *supra* note 29, at 164-71.

elements, which lead to increased uptake of toxic substances in the environment.

Because leaded paint and aging water systems, especially in decaying urban areas, can be a significant source of lead and manganese, the data presented here probably underestimate the effects of toxic metals. A study now underway is analyzing towns and cities in Massachusetts to assess the effects of lead in public water supplies on a number of behavioral measures.[36] Preliminary findings show that higher average levels of lead correlate with lower standardized educational test results, increased high school drop-out rates, increased numbers of single-parent families, and increased crime rates.[37] Indeed, controlling for other socioeconomic and demographic variables, lead seems to be one of the strongest factors in predicting rates of both violent and property crimes.

Because calcium, zinc or other vitamin and mineral insufficiencies are associated with uptake of lead and manganese, differential vulnerability to toxic chemicals must be considered in explaining high rates of violent crime, particularly among population groups with poor diets and low levels of breast feeding. As a number of studies have shown, blacks are differentially vulnerable to the uptake of toxic metals such as lead.[38] Indeed, it would seem that *all* of the effects analyzed in the *Bell Curve*,[39] especially with regard to black-white differences in intelligence and crime, can be traced to differential exposure to, and differential uptake of, neurotoxic metals.[40]

V. PRELIMINARY IMPLICATIONS FOR THE LAW

This biological perspective on violent behavior diverges from contemporary sociological and legal conceptions of crime and criminals in a number of ways. On the one hand, it is unlikely that any single risk factor for violence will provide a satisfactory explanation of criminal behavior; rather, multiple factors, including the offender's chosen lifestyle, interact to explain any one instance of criminal violence. If this is so, there is no need to alter traditional notions of mens rea, and hence of legal responsibility, due to the

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36. This work, being conducted with Myron Coplan of Intellequity, located in Natick, Massachusetts, utilizes a database developed by Prof. Adrian Bailey of the Department of Geography o Dartmouth College, and his colleagues, extending it to include rates of crime and levels of lead in publi water supplies.

37. *See* Masters et al., *supra* note 29.

38. *See infra* Figure 6.

39. RICHARD J. HERRNSTEIN & CHARLES MURRAY, THE BELL CURVE: INTELLIGENCE AND CLASS STRUCTURE IN AMERICAN LIFE (1994).

40. For evidence of the differential vulnerability of blacks to neurotoxins, see Masters et al., *supra* note 30, at 164-71.

discovery of objective factors that modify human brain chemistry and central nervous system function. Because diet, consumption of alcohol or psychoactive drugs, and preferred patterns of social behavior can influence the brain's capacity to inhibit aggressive impulses, knowledge of risk factors influencing neurochemistry and emotional responsiveness should not be viewed as disculpatory. The so-called "Twinkie defense"—which in any event has never been broadly accepted—would be both imprudent and unnecessary as a legal application of the biological findings described in this symposium.[41]

On the other hand, however, both crime prevention and effective sentencing need to consider a broader range of risk factors than has hitherto been customary. In particular, insofar as there are differences in the factors leading to violent crime, offenders guilty of the same offense should probably receive different punishments or probationary conditions. Such a trend will, however, pose serious problems for the law because case disposition would increasingly have to be based on the actor and not the act. In place of mandatory sentencing and the notion that all those convicted of a given offense deserve identical punishments, it would become essential to find out what made each violent offender different from nonviolent offenders.

For example, at the minimum, it will be necessary to distinguish between episodic or low risk criminals and repeat offenders (like those described by Professor Denno), who commit a large number of crimes even though they are a small proportion of the population.[42] Rehabilitation seems least promising for those who have been called "primary psychopaths" or for whom there is a physiological deficit in integrating emotion and cognition (like Phineas Gage, whose abnormal social behavior was described at this symposium by Oliver Goodenough).[43] In contrast, criminal offenders with reversible neurochemical deficits may occasionally commit violent acts but be more likely to be influenced by measures of prevention and treatment.

This distinction may be particularly relevant to what has been described as the epidemic of violence in American society. Rates of violent crime vary enormously from one city or county to another. Since the population frequency of primary psychopathy has been viewed as roughly constant across many social and cultural circumstances, irreversible genetic or neuroanatomical deficits are not likely to explain the most salient dimensions

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41. *See generally* WILSON, *supra* note 2 (arguing that the tendency to allow social scientific explanations of behavior to generate disculpatory evidence is undermining our criminal law, with serious implications for the public support for our legal system).

42. *See* Denno, *supra* note 21, at 311.

43. *See* Oliver R. Goodenough, *Biology, Behavior, and Criminal Law: Seeking a Responsible Approach to an Inevitable Interchange*, 22 VT. L. REV. 263 (1997).

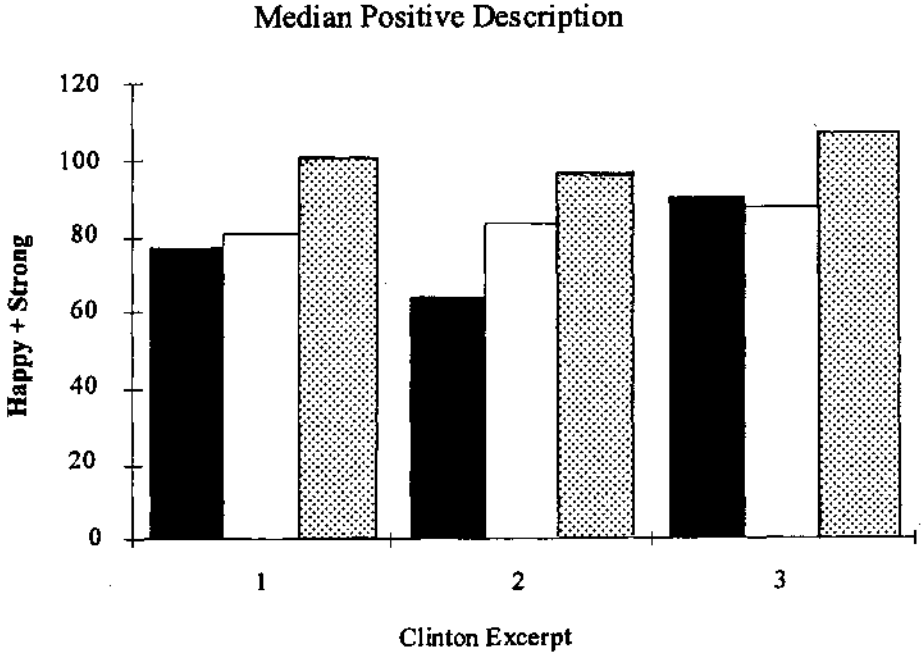
of violent crime in American society. Paradoxically, biology can suggest some environmental risk factors that might distinguish repeat offenders from the episodic offenders.

Figure 1

MEDIAN DESCRIPTIVE RATINGS — VERMONT PRISON INMATES

VIOLENT OFFENDERS (BLACK BARS, n = 17)
NONVIOLENT OFFENDERS (WHITE BARS, n = 15)
NONPRISONEER CONTROLS (GREY BARS, n = 89)

VIEWING NEUTRAL EXCERPTS OF CLINTON



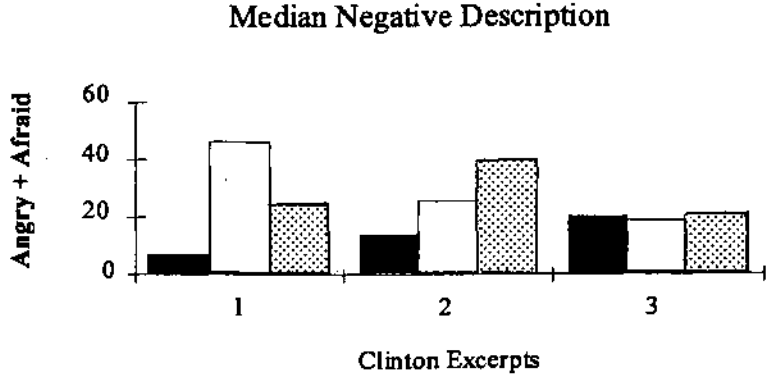
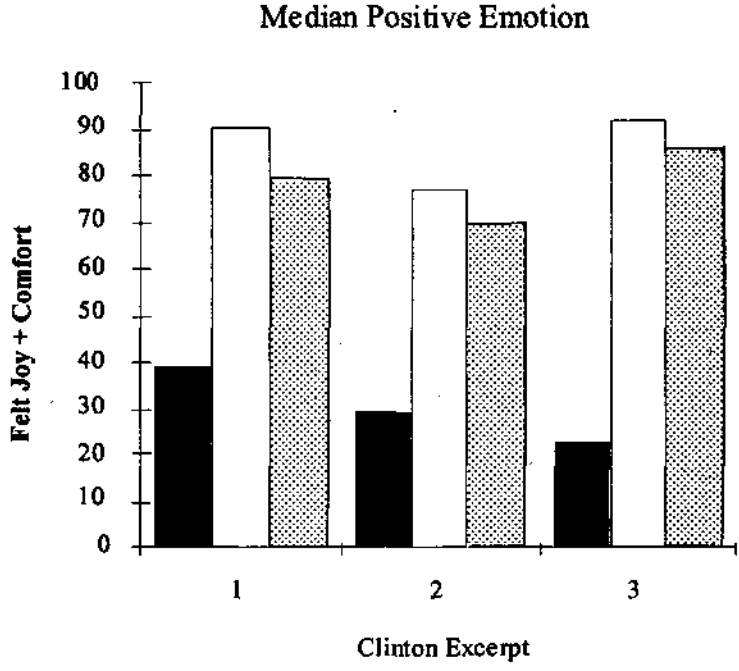


Figure 2

MEDIAN EMOTIONAL RESPONSES - VERMONT PRISON INMATES

VIOLENT OFFENDERS (BLACK BARS, n = 17)
NONVIOLENT OFFENDERS (WHITE BARS, n = 15)
NONPRISONER CONTROLS (GREY BARS, n = 89)

VIEWING NEUTRAL EXCERPTS OF CLINTON



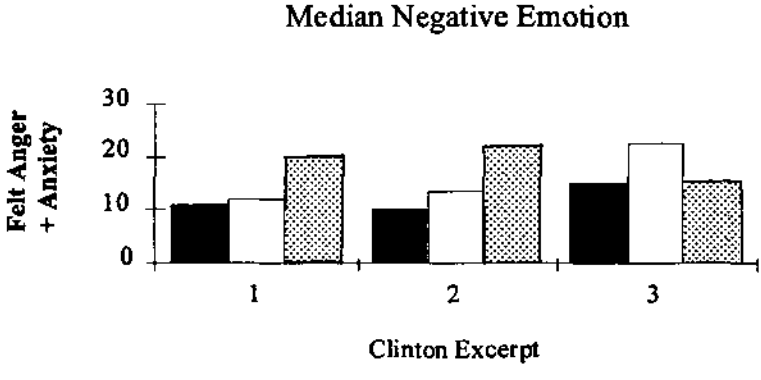
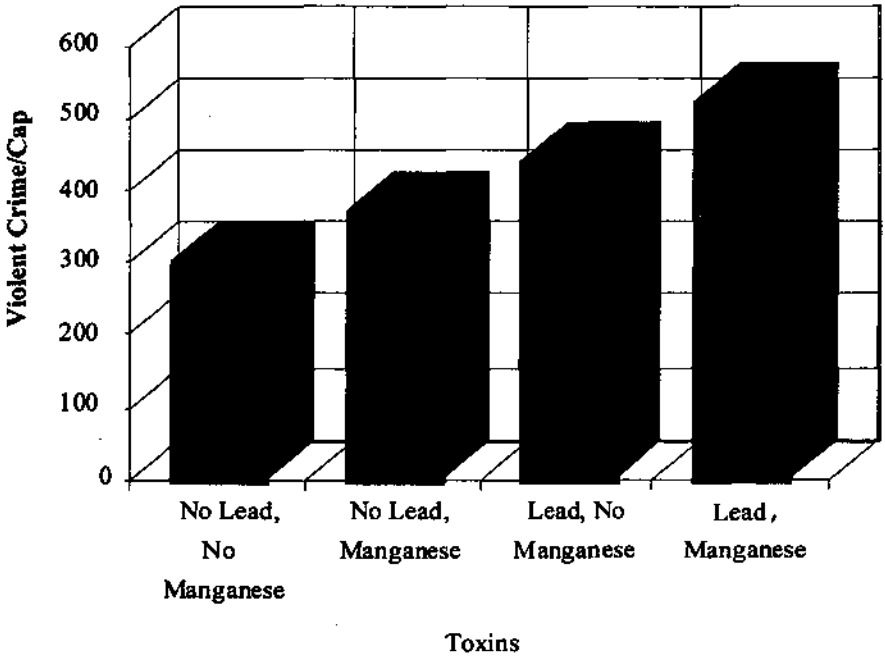


Figure 3

Toxic Release of Lead and Manganese as a Predictor of Rates of Violent Crime, by County

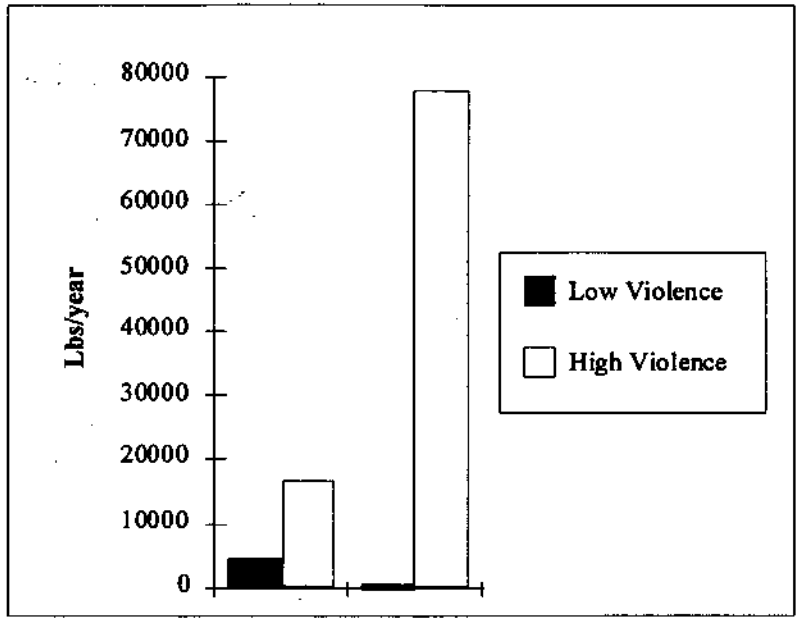
(16 State Sample, 1165 Counties)



Source: FBI Crime statistics, 1991 (total rate of homicide, aggravated assault, sexual assault, and robbery). Total releases of toxic metals: Environmental Protection Agency, Toxic Release Inventory, 1991. Parentheses: number of counties. Data from 1141 counties (24 counties deleted from sample for missing data). Significance: total manganese release: $p = .0039$, $F_{1,1137} = 8.36$; total lead release: $p = .0001$, $F_{1,1137} = 31.22$; interaction between manganese and lead, n.s.

Figure 4
Annual Toxic Release Inventory of Manganese and Lead in Counties with Low and High Crime Rates

(16 State Sample, 1165 counties)



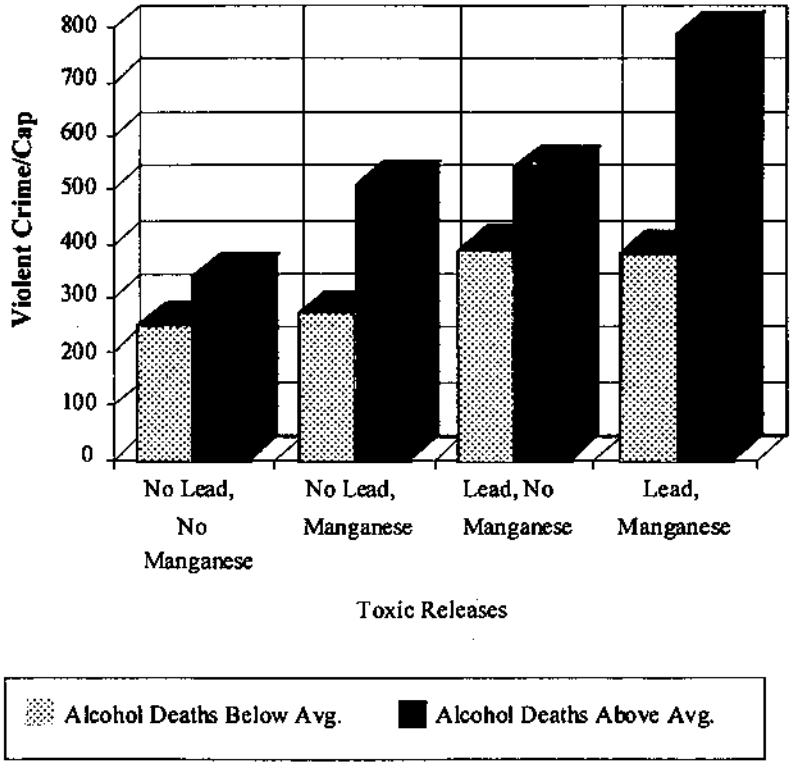
Low violence counties (n = 255): < 100/100,000 per year
High violence counties (n = 310): > 400/100,000 per year
Statistical significance: Manganese, p = .0094; Lead, p =.0027
(1 tailed Chi-square)

Note: The effects shown above can be confirmed by "contingency" analysis. Approximately three-fourths of counties in the total sample had no reported release of either manganese or lead. Among counties within top 10% in lead toxicity for the entire sample, with releases of over 8594 pounds per year, 48 had above average rates of violent crime (greater than 400/100,000) and only 1 had a rate below 100/100,000. Of the 47 counties in the top 10% of manganese toxicity (5879 pounds per year), 32 had above average rates of violence and only 15 had rates below 100/100,000. Similar effects could be seen for low levels of toxic release (less than 8594 pound of lead or 5879 pounds of manganese). Counties with no reported release of lead or manganese were about equally divided between high and low violence rates. This statistical measure of the correlation between toxic metals and violent crime is also highly significant (lead, p = .0001; manganese, p = .0008)

Figure 5

Association of Manganese and Lead Pollution and Rates of Alcoholism with Violent Crime

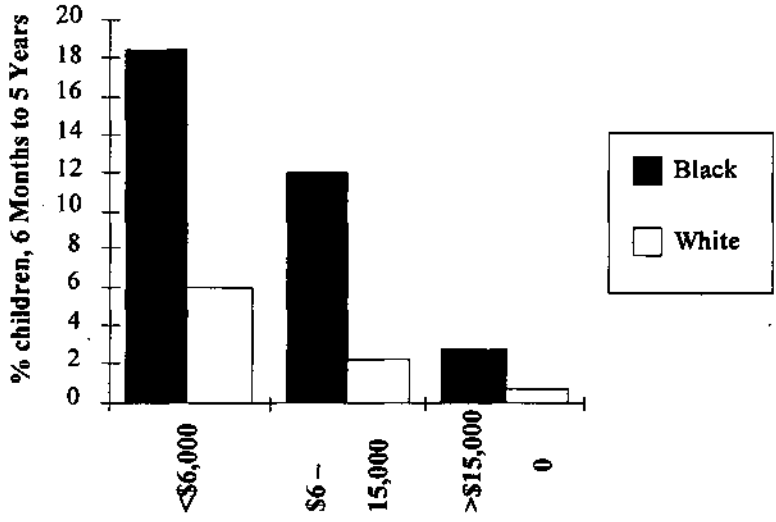
(16 State Sample, 1165 Counties)



NOTES: Three-way ANOVA, data from 1119 counties (22 counties from Table 3 deleted for missing data on alcoholism). Rates of Death from Alcoholism dichotomized at average (42.4/100,000 per year). Significance of main effects: Presence or Absence of Manganese Pollution (TRI): $p = .0001$, $F_{1,1111} = 16.836$; Lead Pollution (TRI): $p = .0001$, $F_{1,1111} = 48.114$; Alcoholism: p. .0001, $F_{1,1111} = 70.217$. Significance of interactions: Manganese and alcoholism: $p = .0001$, $F_{1,1111} = 15.512$; Lead and Alcoholism: $p = .0347$, $F_{1,1111} = 4.473$.

Figure 6

Percent Children with PbB > 30ug/dL, by Family Income



Source: Jane S. Lin-Fu, "Modern History of Lead Poisoning," in Herbert Needleman, ed., *Human Lead Exposure* (Boca Raton, FL: CRC Press, 1992), Table 2, p. 37; data from NHANES II Survey (1976-1980).