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LEAD EXPOSURE AND ITS IMPLICATIONS FOR CRIMINOLOGICAL THEORY

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This article summarizes what is known about the association between lead exposure and human behavior and discusses the implications for criminology. It provides background information about lead sources and measurement and traces the various impacts of lead exposure on humans, including cognition and behavior. It posits that the link between lead exposure, aggression, delinquency, and crime is consistent with the traditional individual-level psychological based and aggregate-level sociological based theories that explain delinquent and criminal behavior and that differential lead exposure and treatment by neighborhood is congruent with theories of social disadvantage. It concludes by enumerating the unsettled debates about the impact of lead exposure and by outlining the profitable avenues for future criminological research.

Keywords: lead; biosocial; crime; neuropsychological deficits; cognitive functioning

Despite growing evidence documenting the relationship between lead exposure and antisocial behavior, there is a dearth of criminological research on this topic. Overall, this body of research by neurologists, epidemiologists, and medical doctors suggests that lead exposure is related to physical, mental, and behavioral deficits (Binns, Campbell, & Brown, 2007), which in turn may be conducive to criminal behavior. Studies also report a direct correlation between individual lead exposure and delinquency/crime as well as aggregate lead levels and crime rates at the ecological level (e.g., Denno, 1990; Needleman, Riess, Tobin, Biesecker, & Greenhouse, 1996; Stretesky & Lynch, 2004). The Centers for Disease Control (CDC) currently estimates that approximately 310,000 U.S. children aged 1 to 5 years and 1.7 million youth in the crime-prone teenage years have blood lead levels greater than the CDC's established level of safety (Brody et al., 1994; CDC, 2008). In addition, lead levels tend to be higher in structurally disadvantaged communities (Hird & Reese, 1998; Lanphear, Dietrich, & Berger, 2003; Stretesky & Lynch, 2001, 2004). Thus, lead exposure is an important and relevant issue for criminologists.

The objective of this article is to review and integrate the evidence regarding the association between lead exposure, structural disadvantage, and crime more firmly into criminological dialogue. Indeed, the link between lead exposure, aggression, delinquency, and crime is consistent with many of the traditional theories of crime and/or delinquency. Differential lead exposure and treatment by neighborhood is also congruent with theories of social disadvantage. To integrate these literatures, the article begins with background

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information on lead sources and measurement, followed by the various impacts of lead exposure on humans, including cognition and behavior. The article then traces the potential linkage between the effects of lead exposure and traditional criminological theories. Specifically, a discussion of how the lead literature can be integrated with micro-, macro-, and cross-level explanations of delinquent and criminal behaviors is presented. The article concludes with a discussion of the implications of the lead and crime relationship and avenues for future criminological research.

BACKGROUND: LEAD SOURCES AND MEASUREMENT

SOURCES OF LEAD

Lead is an organic metal that for centuries has been mined for industrial use (Needleman & Bellinger, 1991). Due to its vast use in industry, lead can be present in the soil, air, and water (Needleman & Bellinger, 1991). Airborne lead, for example, is the result of the emissions of automobiles, smelters, battery plants, and industrial facilities (Needleman & Bellinger, 1991; Stretesky & Lynch, 2001, 2004). Lead can also be present in residential homes. For example, lead in household plumbing may contaminate drinking water (Lanphear et al., 1996; Lanphear et al., 2002; Lanphear et al., 2003; Needleman & Bellinger, 1991; Nevin, 2000). Food is another documented source of lead (Lanphear et al., 2003; Mielke & Reagan, 1998; Needleman & Bellinger, 1991; Silbergeld, 1990). Lead is taken up by crops, particularly root vegetables (i.e., radishes, potatoes, and carrots), when they are planted in contaminated soil (Needleman, 2004). In addition, some crops near heavily traveled roads accumulate atmospheric lead deposited on them by airborne lead emissions (Needleman, 2004). The processing, use of preservatives, and use of soldered cans may also contaminate food and increase the risk of lead exposure from purchases (Needleman, 2004; Pirkle et al., 1994). Finally, lead-based paint is a common problem in older houses because prior to the 1970s, lead was used as a material in paint to speed up drying, improve durability, and maintain a fresh appearance. Lead paint that has not been removed in these older houses transforms into dust and paint chips (Lanphear et al., 1996) that children can swallow (CDC, 1997a).

It is difficult to determine which sources of lead (i.e., soil, air, food, or paint) present the greatest potential for lead exposure/poisoning. The most common pathway to exposure likely varies by group (i.e., dietary intake may be a predominant source of lead exposure for adults whereas ingestion of indoor paint dust may be a more common pathway for children), but lead from any of these sources can be ingested or inhaled into the body. The health effects are not limited to the point of entry because lead moves into the blood stream (Environmental Protection Agency, 2008). On entering the blood stream, the vast majority of lead (approximately 99%) attaches to red blood cells, meaning it quickly spreads throughout the entire body (Environmental Protection Agency, 2008).

MEASURES OF LEAD

Because of the biological process, scholars most often use direct measures of lead exposure. Blood lead level (measured as micrograms of lead per deciliter of blood) is the most common method used to measure individual body lead burden (Bellinger et al., 1991; Tong, Baghurst, Sawyer, Burns, & McMichael, 1998). In fact, the CDC uses blood lead tests to set guidelines for treatment of various exposure levels. CDC guidelines currently place blood lead levels of 10 ug/dl or more as the actionable limit for lead exposure (CDC, 1991). Prior to 1991, the CDC maintained a threshold of 25 ug/dl, but the CDC revised this limit in the face of mounting evidence that lead levels less than 25 ug/dl have negative effects on humans (Needleman, 2004). Today, the CDC considers blood lead levels from 0 to 10 ug/dl to be low-level exposure but acknowledges in the report *Preventing Lead Poisoning in Young Children* (CDC, 1991) that there is no "safe" threshold for blood lead (Environmental Protection Agency, 2008). Blood lead levels from 11 to 25 ug/dl are considered moderate-level exposures; doctors recommend that children diagnosed within this range be regularly screened (Roper, 1991). Finally, blood lead levels ranging from 25 to 70 ug/dl are considered high-level exposures and need immediate medical treatment. Patients are considered lead poisoned when blood lead levels range beyond 70 ug/dl.

Scientists also measure the lead body burden using bone lead levels (Needleman et al., 1996; Needleman, McFarland, Ness, Fienberg, & Tobin, 2002). Because lead is stored in the bones, bone measurements are considered a better measure of cumulative lead exposure during the lifetime than blood lead levels, whereas blood lead levels are thought to measure exposure that is more recent. However, because the blood is in contact with bones, blood lead may be a measure of recent or historical exposure. In addition, because of rapid growth, bone lead levels are more likely to change in children than in adults. Thus, changes in blood lead concentration in children are a closer approximation of total body burden (Environmental Protection Agency, 2008). Other scientists make use of hair lead levels (Pihl & Ervin, 1990) and dentine deposits (Arora et al., 2006; Fergusson, Horwood, & Lynskey, 1993).

Ecological studies aggregate the aforementioned measures to capture lead exposure at the macro level. For example, neighborhood-level blood lead levels (i.e., the percentage of children with blood lead levels greater than the "safe" limit) are a common measure. In addition to blood lead counts, many studies also have employed lead emissions data to capture lead levels in the ecological environment, including the Environmental Protection Agency's Toxic Release Inventory (Masters, Hone, & Doshi, 1998) and the Environmental Protection Agency's Cumulative Exposure Project of 1990 (Stretesky & Lynch, 2001, 2004). The Toxic Release Inventory contains information about toxic chemical releases into the air by smokestacks and fugitive sources (i.e., leaking valves); into streams, rivers, lakes, and the ocean by industrial discharge pipes; and into land through placement in landfills. The Toxic Release Inventory reports only legal emissions into the environment. Therefore, there is currently a dearth of knowledge about the amounts of lead released by industries illegally. The Cumulative Exposure Project, compiled in 1990, draws on Toxic Release Inventory data and other sources of air lead (e.g., mobile sources) to provide measures of lead levels in the air by county (micrograms per cubic meter) (Stretesky & Lynch, 2001, 2004). Finally, researchers also utilize estimates of the annual consumption of lead in gasoline and lead in paint from the U.S. Geological Survey (Nevin, 2000).

At both the individual and ecological levels, scientists have explored the correlation between lead concentrations and human functioning and/or behavior. In the following section, a review of the individual-level and then the ecological studies is presented. Although the individual-level studies have often examined noncrime outcomes such as IQ, hyperactivity, and school performance, these factors are quite relevant to criminologists because many of them are related to delinquency and crime. Other studies (individual and ecological) assess the direct relationship between lead levels and delinquency/crime.

THE EFFECT OF LEAD ON HUMANS

INDIVIDUAL-LEVEL LEAD STUDIES

Mental and cognitive functioning. Studies have documented the effects of lead exposure on mental and cognitive functioning in children and the elderly. Several studies have indicated that low levels of exposure have negative effects in children (e.g., disturbances in motor functions) even after controlling for socioeconomic status, demographics, and family characteristics (Bellinger et al., 1991; Dietrich, Berger, Succop, Hammond, & Bornschein, 1993; Wasserman et al., 2000). For example, Bellinger et al. (1991) reported an inverse association between blood lead level and visual-spatial and visual-motor integration skills, controlling for family social class, maternal IQ, preschool attendance, home score (i.e., Home Observation for Measurement of the Environment Scale, which measures how the environment in the household meets a child's needs), hours per week out of home care, number of family residence changes since the child's birth, medication, and number of adults in the family.

At moderate to lower levels of exposure (25 and fewer ug/dl), lead was also associated with a lower IQ when gender, parent's level of education, and other important confounding variables were held constant (Baghurst et al. 1992; Bellinger, Stiles, & Needleman, 1992; Canfield et al., 2003; Dietrich et al., 1987; Needleman et al., 1979; Schnaas et al., 2006; Tong et al., 1998). The effect of lead on IQ also was documented among infants (Bellinger et al., 1991; Bellinger, Leviton, Waternaux, Needleman, & Rabinowitz, 1987; Dietrich et al., 1987). In a study of 249 infants, those with blood lead levels of 10 to 25 ug/dl (measured prenatally with umbilical cord blood and postnatally with capillary blood samples) scored significantly lower in the Bayley's Scale Mental Development Index than participants with lower blood lead levels after adjusting for potential confounders (Bellinger et al., 1987). Other studies have shown that moderate to low-level exposures have an effect on the IQs of younger children (Baghurst et al., 1992; Bellinger et al., 1991; Bellinger et al., 1992; Dudek & Merecz, 1997). More recently, Canfield and colleagues (2003) found that after controlling for maternal IQ, quality of home environment, and other potential confounders, IQ declined by 7.4 points as lifetime average blood lead concentrations increased from 1 to 10 ug/dl. These findings have been replicated in countries other than the United States (e.g., Baghurst et al., 1992; Schnaas et al., 2006).

Researchers also have found a relationship between other mental and cognitive deficits and moderate/low-level exposures to lead. For example, some studies have found a relationship between lead exposure and impaired reaction time (Lansdown, Yule, Urbanowicz, & Millar, 1983; Needleman et al., 1979), disorganization (Fergusson, et al., 1993; Lansdown et al., 1983; Sciarillo, Alexander, & Farrell, 1992), and verbal and speech deficiencies (Coscia, Douglas, Succop, & Dietrich, 2003; Lansdown et al., 1983; Needleman et al., 1979). Other studies have documented the impact of lead on school performance, including deficits in mathematical skills (Lanphear, Dietrich, Auinger, & Cox, 2000; Lanphear et al., 2003), learning and reading disabilities (Fergusson et al., 1993; Fergusson, Horwood, & Lynskey, 1997; Lanphear et al., 2000; Needleman, Schell, Bellinger, Leviton, & Allred, 1990), lower examination scores (Fergusson et al., 1997), and dropping out of school (Bellinger, Needleman, Bromfield, & Mintz, 1986; Fergusson et al., 1997; Needleman et al., 1990).

Some researchers (i.e., Kaufman, 2001a, 2001b; Pocock, Smith, & Baghurst, 1994) have posited the relationship between IQ and lead may be a product of reverse causality. That is, children with low IQs are more likely to place themselves into situations that increase their odds of lead exposure. Studies that have measured perinatal or prenatal BPb concentrations (e.g., Bellinger et al., 1987; Dietrich, Douglas, Succop, Berger, & Bornschein, 2001; Tong et al., 1998; Wright et al., 2008), however, suggest that this might not be the case. IQ and conduct disorders are related to prenatal and neonatal BPb concentrations, rejecting the reverse causality argument.

Finally, in addition to direct associations, research has suggested that lead levels interact with the social environment. For example, Douglas, Dietrich, Succop, Berger, and Bornchein (2004) found that the negative relationship between lead level and cognitive development is exacerbated in families of low socioeconomic status. Similarly, other studies have found that higher neonatal blood lead levels are associated with poorer performance on all Kaufman-Assessment Battery for Children (K-ABC) subscales only among children from the poorest families (Dietrich, Succop, Berger, Hammond, & Bornschein, 1990). In general, these studies have suggested that children from families in lower socioeconomic groups are more vulnerable to the effects of lead than children of higher economic status (Bellinger, Leviton, Waternaux, Needleman, & Rabinowitz, 1988).

Behavioral problems. Numerous studies have also shown the effect of lead on externalizing behaviors (i.e., hyperactivity, inattentiveness, restlessness, and aggression) (Bellinger, Leviton, Allred, & Rabinowitz, 1994; Dudek and Merecz, 1997; Fergusson et al., 1993; Lansdown et al., 1983; Needleman et al., 1979; Needleman et al., 1996; Silva, Hughes, Williams, & Faed, 1988; Thompson et al., 1989). For example, Needleman et al. (1979) found that first- and second-grade children with elevated dentine lead levels (but no symptoms of plumbism or lead poisoning) were less attentive in class according to teacher ratings. Lead was also associated with higher scores on the inattentive-passive and hyperactive scales of the Connor questionnaire (Lansdown et al., 1983). Similarly, after controlling for various confounders, Fergusson, Fergusson, Horwood, and Kinzett (1988) found a positive relationship between dentine lead levels and maternal and teacher ratings of inattentive/restless behavior. More recent studies have replicated these findings (Bellinger et al., 1994; Dudek & Merecz, 1997; Fergusson et al., 1993; Needleman et al., 1996; Silva et al., 1988; Thompson et al., 1989) and have suggested a relationship between lead exposure and Attention Deficit Hyperactivity Disorder (ADHD) (Braun, Kahn, Froehlich, Auinger, & Lanphear, 2006; Nigg et al., 2008).

In addition to attention deficits and distractibility, researchers have found a relationship between lead exposure and conduct disorders and aggression (Chen, Cai, Dietrich, Radcliffe, & Rogan, 2007). Specifically, teachers and parents were more likely to report that children with high lead exposure misbehave in school and at home. Sciarillo and colleagues (1992) and Needleman and colleagues (1996) found that maternal and teacher reports of conduct disorders and maladaptive behaviors were higher for children who experienced moderate levels of lead exposure. In one of the first studies of its kind, Byers and Lord (1943) reported that children treated for acute plumbism also exhibit violent and aggressive behavioral difficulties (e.g., attacking teachers). More recently, Needleman and colleagues (1996) found that lead-exposed children exhibit an increased risk for antisocial behavior. Specifically, the teachers of these children were more likely to report aggression among the lead exposed than among the nonexposed group even after controlling for nine social and familial covariates. Interesting to note, the association increased with age. Both the parents and the teachers of the children reported that the children's behavior worsened from age 7 to 11 (Needleman et al., 1996).

Delinquency and crime. Individual lead levels were also linked to delinquency and crime. Denno (1990) traced the behavioral patterns of 987 African American youth (487 males and 500 females) from birth to 22 years of age. After controlling for environmental and social factors, such as parents' income and occupation, she found that among males, early childhood lead poisoning was one of the most important predictors of (a) disciplinary problems from ages 13 to 14, (b) juvenile delinquency from ages 7 to 17, and (c) the number of adult offenses from ages 18 to 22. Pihl and Ervin (1990) also found a relationship between hair lead levels and conviction crime type after controlling for age, socioeconomic status, months institutionalized, and drug use history. Specifically, violent offenders were more likely than property offenders to have elevated levels of hair lead.

Subsequent research has also found a relationship between lead exposure and crime. With a sample of 301 Pittsburgh grade-school children, parents and teachers were more likely to rate as delinquent the behaviors of children with high bone lead levels than the behaviors of children with low lead levels (Needleman et al., 1996). Children with higher lead levels also reported engaging in more delinquent acts. Similarly, prenatal exposure to lead was associated with an increased frequency of self-reported and parent-reported delinquency acts, a relationship that remained significant even after controlling for medical, social, and family risk factors (Dietrich et al., 2001). Dietrich and colleagues (2001) also found a relationship between prenatal exposure to lead and parental reports of children's antisocial behavior. Specifically, the researchers found that on average, (a) participants in the highest prenatal blood lead category engaged in 2.3 more delinquent acts during the preceding 12 months than participants in the lowest category, (b) participants in the medium and highest average childhood blood lead category engaged in approximately 1.5 more delinquent acts than participants in the lower categories, and (c) participants in the highest 78-month blood lead category engaged in 4.5 more delinquent acts than participants in the lowest category.

Additional studies with different methodologies have also found a relationship between lead and delinquent behavior. For example, Needleman and colleagues (2002) found that adjudicated delinquents had higher bone lead levels than nondelinquents. Adjudicated delinquents were four times more likely than nondelinquents to have bone lead concentrations higher than 25 parts per million. In this study, bone lead level was the second strongest delinquency risk factor, exceeded only by race (Needleman et al., 2002). More recently, Wright et al. (2008) found a direct relationship between blood lead levels and future arrests after controlling for maternal IQ, sex, socioeconomic score, maternal education, and other covariates of crime. Prenatal and childhood lead concentrations were positively associated with total and violent arrests. Specifically, for every 5 ug/dl increase in prenatal, childhood, and blood lead levels at age 6, the number of arrests per year increased by 0.48, 0.13, and 0.39, respectively. The number of violent arrests per year increased by 0.06, 0.08, and 0.09 as the prenatal, childhood, and age 6 blood lead levels increased by 5 ug/dl. Finally, Fergusson, Boden, and Horwood (2008) found a positive relationship between dentine lead levels at ages 6 to 9 and officially recorded violent/property convictions and self-reported violent/property offending at ages 14 to 21. This relationship largely operated through the inverse impact of lead exposure on educational achievement.

AGGREGATE-LEVEL LEAD STUDIES

Delinquency and crime. The individual-level association between lead exposure, delinquency, and crime prompted social scientists to examine the association between lead and crime rates using ecological units of analysis. Researchers have found a significant relationship between county-level crime rates and atmospheric lead (Masters et al., 1998; Stretesky & Lynch, 2001, 2004). Specifically, county lead levels were related to violent and property crime rates even after controlling for key variables such as income, population density, and ethnic composition (Masters et al., 1998). Air lead levels were also associated with county-level homicide rates. In fact, lead concentration was the only indicator of air pollution significantly associated with homicide rates (Stretesky & Lynch, 2001). After adjusting for 15 potential confounding variables, homicide rates in the counties with the highest lead levels were four times higher than homicide rates in the lowest lead counties. In a more recent study, Stretesky and Lynch (2004) examined the relationship between air lead levels and violent and property crime rates, controlling for confounding variables such as socioeconomic status. The relationship between air lead levels and crime rates (property and violent) was strongest in counties that had high levels of resource deprivation and weakest in counties that had low levels of deprivation (Stretesky & Lynch, 2004).

Finally, decreases in lead emissions were also linked to national crime trends, including the dramatic drop in violent crime in the mid-1990s. Nevin (2000) hypothesized that increased consumption of leaded gasoline in the 1960s to mid-1970s elevated the risk of lead exposure among children born during that period. Specifically, he posited that lead exposure might have lowered intellectual ability among this age group, resulting in poor decision making during teenage and young adult years that would eventually translate to an elevated risk of criminal involvement and thus higher aggregate crime rates during the mid- and late 1980s. Empirically, Nevin found an association between per capita consumption of gasoline and violent crime rates as well as violent crime and gasoline lead trends from the 1960s to the mid-1990s after controlling for abortion rates, unwed birth rates, maternal education, economic status, and family demographics. Nevin, however, did not control for some important structural and criminal justice factors associated with crime. In 2007, Reyes replicated and expanded Nevin's work. Using state-level observations to identify the connection between lead exposure and crime for the 50 states and the District of Columbia, she examined the relationship between lead consumption and state violent crime rates, controlling for important social structural confounders (i.e., unemployment rate, per capita income, poverty rate, Aid to Families With Dependent Children, population aged 15 to 29, and teen pregnancy rate), criminal justice confounders (i.e., prisoners per 100,000 population and police officers per 100,000 population), and other (i.e., per capita beer consumption) confounders (Reyes, 2007). Her findings suggested that the phaseout of lead from gasoline in the 1970s might have been responsible for a 56% decline in violent crime between 1992 and 2002.

THE DISTRIBUTION OF LEAD: ECOLOGICAL AND GROUP PATTERNS

Ecological research has shown wide variation in environmental lead levels, ranging from estimated air lead concentrations of 0 to 0.17 ug/m3 across U.S. counties (Stretesky & Lynch, 2001, 2004). In these studies, variation in lead levels was not random. For example, the distribution of lead was also related to the demographic composition of the ecological unit. African Americans and Hispanics were more likely than Caucasians to reside in counties in the United States that had high lead emission rates (Hird & Reese, 1998). In fact, counties with the largest proportion of African American youth had 8% more lead in the air than counties with no African American youth (Stretesky, 2003). This distribution was likely the result of lower socioeconomic class and minority groups' living in urban areas located near major highways or industrial zones or in rural areas near mining or smelter sites (Malcoe, Lynch, Keger, & Skaggs, 2002; Mielke & Reagan, 1998; Nevin, 2000). Needleman and Bellinger (1991) projected that lead concentrations in soil within 25 meters of major roadways were as high as 2,000 ppm and as high as 60,000 ppm near smelters (Needleman & Bellinger, 1991). In addition, these groups have tended to reside in lower income and rental housing, which are more likely to have lead-based paint (Lanphear et al., 2003). Indeed, Nevin (2000) noted that inner-city children have experienced little benefit from declining levels of lead in paint in the general population because there has been little success in the removal of lead-based paint in these areas. In addition, unlike their Caucasian counterparts, African Americans and Hispanic Americans could not easily flee lead-prone neighborhoods because of economic constraints (Stretesky & Lynch, 2004). Finally, inner-city African American communities have tended to be poorly organized and consequently unable to resist the emission of industrial pollutants into their neighborhoods. As Warren (2000) documented, various social, political, and economic forces have influenced the production, consumption, and distribution of lead across the urban and rural landscape, leaving the politically powerless more exposed.

The unequal geographic distribution of lead has led to different patterns of exposure by group (Hird & Reese, 1998). For example, significant racial disparity in blood lead levels has been documented (Lanphear et al., 2003). Studies repeatedly have found significantly higher blood lead levels among African American children than Caucasian children (Brody et al., 1994; Lanphear et al., 2002; Pirkle et al., 1994). For example, between 2001 and 2004, the average blood level for Black (non-Hispanic) children was 2.5 ug/dl, the average for Black children living in poverty was 2.9 ug/dl, and the average blood lead levels for Black children at the 90th percentile was 6.4 ug/dl (Environmental Protection Agency, 2008). Hispanic American children fell in the middle, with their blood lead levels slightly lower than those of African Americans but significantly higher than those of Caucasians (Lanphear et al., 2003); this was particularly seen among African American and Hispanic children who had lived in older housing. Similar disparities by socioeconomic status have been documented. The average blood level for U.S. children ages 1 to 5 during the same period was 1.6 ug/dl. The average blood lead level for children living in poverty was 2.3 ug/dl. At the 90th percentile of children living below the poverty line, the average blood lead level was 5.4 ug/dl (Environmental Protection Agency, 2008).

In addition to differential exposure, studies have suggested that minorities and the poor are less likely than Caucasians and the affluent to be effectively screened and treated when exposed to lead (Brody et al., 1994; Kraft & Scheberle, 1995; Pirkle et al., 1994; Reed, 1992). In 1997, the CDC reported that only 20% to 30% of children living in poverty (a high-risk group for lead poisoning) had been screened for lead exposure (CDC, 1997b). Medical personnel, facilities, and treatment have also not been sufficient in poor communities even when children have been screened and diagnosed with lead exposure (Lanphear et al., 2003). The U.S. General Accounting Office reported that most children who received federal aid such as Medicaid were not adequately screened for lead poisoning and that there was little government oversight and enforcement regarding lead poisoning detection and prevention in deprived communities (General Accounting Office, 1999).

In sum, the individual- and ecological-level studies suggest an association between structural disadvantage, lead exposure, aggression, and crime/delinquency. However, there is still a considerable debate among scholars about whether the individual-level relationship is causal (see Kaufman, 2001a, 2001b). Although additional research is needed on the dose-response relationship and the potential for omitted variable bias (discussed below), several of the criteria for evaluating environment-disease associations (i.e., the criteria that can be assessed by criminologists) support an argument of causality. For example, the associations between lead exposure and physical, neuropsychological, and behavioral impairments are generally consistent across samples (e.g., convicted populations, school children), lead measures (e.g., dentine, blood, bone, and hair levels in prenatal, childhood, and adult measurements), locations (e.g., United States and abroad), and species (i.e., human and animal studies). In addition, when the strength of the association has been reported, scholars have found sizeable effects. For example, Dietrich et al. (2001) found that on average, participants in the highest prenatal blood lead category engaged in 2.3 more delinquent acts during the preceding 12 months than participants in the lowest category. In addition, Wright et al. (2008) found that the number of arrests per year increased by 0.48 for every 5 ug/dl increase in prenatal lead levels. These studies have also established the appropriate temporal order, examining the effect of blood lead levels (in some cases prenatal) on subsequent behavior.

To date, these findings have not been placed in the context of or integrated into criminological theory. This lack of attention may have resulted from an aversion to scholarship on biology and crime among scholars and the U.S. courts (Duster, 2003). Indeed, some social scientists fear that this knowledge may be used to create racist crime policies aimed at African Americans, who make up the bulk of incarceration statistics (Duster, 2003). Other social scientists argue that it is impossible to have confidence in the validity of studies that examine biological predisposition due to methodological problems, such as how crime is defined and the dark figure of crime (Duster, 2003). Yet the implications of the lead-crime-disadvantage relationship span well beyond biological reductionism and can be integrated into biosocial, psychological, and sociological theories of crime and intervention strategies. In addition, the integration of criminological perspectives (e.g., relevant covariates by age, the need to disaggregate by crime type) could inform arguments regarding the causality of the lead-crime association. In the following section, we demonstrate the relevance of the lead-crime-disadvantage relationship for a variety of criminological theories.

INTEGRATING LEAD INTO CRIMINOLOGICAL THEORY

The lead literature makes important contributions to micro-, macro-, and cross-level theories of crime (see Figure 1). First, the individual-level lead literature adds a more distal starting point to flesh out potential biosocial and psychosocial pathways to crime. Second, the ecological-level lead literature introduces a unique component to theories of structural disadvantage and can be integrated into micro-level theories to create richer cross-level theories. Finally, the lack of prevention and treatment of lead exposure in minority communities can be integrated into subcultural theories of crime. Ultimately, this integration moves criminology toward more fully specified theories of crime that acknowledge the biological and psychological impact of lead (and therefore can incorporate other environmental toxins) and its correlation with structural disadvantage.

INDIVIDUAL-LEVEL THEORIES

Although several lead studies document an association between lead levels and crime, delinquency, or crime rates, most studies link lead exposure to mental/cognitive functioning and externalizing behaviors that are known to covary with crime (see Figure 1). For example, lead exposure is related to cognitive deficits such as lower IQ, poor executive functions, impaired reaction time, disorganization, and verbal and speech deficiencies (Baghurst et al., 1992; Bellinger et al., 1986; Bellinger et al., 1987; Bellinger et al., 1992; Canfield et al., 2003; Dietrich et al., 1987; Khalil et al., 2009; Needleman et al., 1979; Schnaas et al., 2006; Stewart & Schwartz, 2007; Tong et al., 1998), all of which are criminogenic (Herrnstein & Murray, 1994; McGloin, Pratt, & Maahs, 2004). The relationship between low IQ, delinquency, and criminal behavior has long been documented in the criminological literature: As IQ decreases, the probability of involvement in delinquent/criminal behaviors increases (Hirschi & Hindelang, 1977). There is also a relationship between criminal behavior, poor executive functions, and verbal deficiencies (Moffitt, 1993). Moffitt (1993) found that verbal and executive function deficits are pervasive among antisocial children. These psychological characteristics are likely a precursor to crime because they lead to low problem solving skills, expressive speech, learning disabilities, and inattention/impulsivity. Related to executive function deficits, childhood lead exposure is also linked to externalizing behaviors such as hyperactivity, inattentiveness, and ADHD (Bellinger et al., 1994; Dudek & Merecz, 1997; Fergusson et al., 1993; Lansdown et al., 1983; Needleman et al., 1979; Needleman et al., 1996; Nigg et al., 2008; Silva et al., 1988; Thompson et al., 1989). Once again, the criminological literature documents an association between ADHD, criminality, and delinquency (Pratt, Cullen, Blevins, Daigle, & Unnever, 2002). Thus, lead may be a more distal predictor of crime than cognitive functioning or externalizing behaviors.

Yet the associations between mental function, externalizing behaviors, and crime/delinquency are not viewed as static biological correlations. Criminologists integrate the cognitive deficits and externalizing behaviors associated with lead exposure into the sociological theories of social and self-control. For example, generally, criminologists do not argue that IQ, in and of itself, causes criminal behavior. Instead, they have hypothesized that low IQ creates problems in the social environment that are in turn criminogenic (Hirschi & Hindelang, 1977; McGloin et al., 2004). Hirschi and Hindelang (1977) found that the relationship between IQ, crime, and delinquency is mediated by poor school performance. Due to poor performance in school, prosocial bonds (i.e., attachment, involvement, commitment, and belief) may be attenuated among children with low IQs. As a result, children with low IQs lack the prosocial controls necessary to prevent them from criminal/delinquent

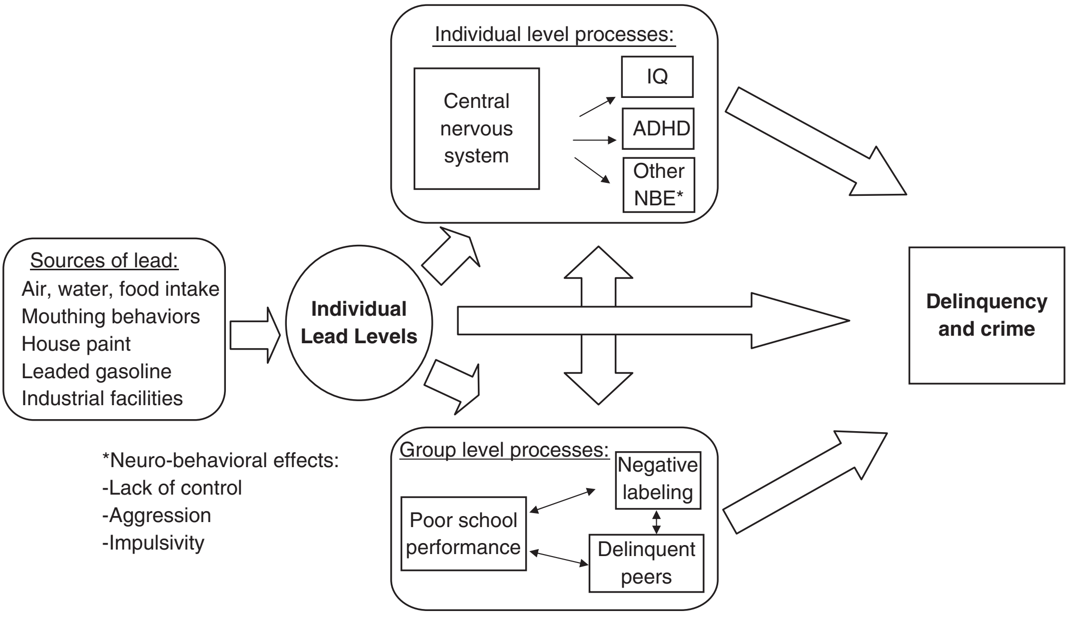

Figure 1: Individual-Level Pathways of Lead Exposure to Delinquent and Criminal Behaviors

involvement. Recent research (e.g., McGloin et al., 2004) has shown also that the IQ-delinquency relationship is mediated by delinquent peers and low self-control. Those with low IQs experience more pressure from delinquent peers. McGloin et al. (2004) hypothesized that frustration arises from poor school performance, leading some children to associate with delinquent subcultures to obtain the status they are not capable of in the school system. In addition, children with low IQ tend to show characteristics of low self-control and impulsivity—behaviors that also may be influenced by exposure to lead. Similarly, the relationship between ADHD and crime is not direct. Instead, ADHD may lead to risk factors for offending, such as poor academic performance, truancy, defiance, low self-control, poor self-regulation, and aggression (Barkley, 1997; Pratt et al., 2002). Research has shown that individuals lacking self-regulation of affect are also more likely to experience a decrease in empathy toward others, a diminished ability to appreciate the consequences of their actions, and a decreased capacity to regulate and control their emotions (Barkley, 1997), all which are conducive to crime. Hence, the integration of the lead and criminological literatures suggests that the cognitive deficits and externalizing behaviors associated with lead exposure may spark a spiral of negative social consequences that are conducive to criminality.

The effects of lead exposure also may be placed in the context of labeling theories. Research suggests that lead-exposed children are more likely to have lower reading and math scores and are more at risk of dropping out and other forms of school failures (Bellinger et al., 1986; Fergusson et al., 1993; Fergusson et al., 1997; Lanphear et al., 2000;

Lanphear et al., 2003). Due to cognitive impairments that may be caused by lead, some children may fail in school and in turn may be labeled as nonperformers. Indeed, Menard and Morse (1984) argued that schools use IQ as a criterion for differential treatment of students. Students tracked into classes for those with lower ability are then negatively labeled and have less access to desirable social roles. The resulting label may block their legitimate involvement in school and community organizations and activities. In addition, instead of being integrated into more conventional values, lead-exposed children may be further alienated if/when they are placed in different classrooms than other children. Negative labels placed on their weak verbal, reading, and other abilities may direct lead-exposed children toward antisocial behavior (Coscia et al., 2003).

MACRO AND CROSS-LEVEL THEORIES

Explanations of criminality. The neighborhood-level lead literature is relevant to theories of structural disadvantage (see Figure 2). As previously described, the distribution of lead varies by neighborhood, with the highest concentrations most often in disadvantaged communities (Hird & Reese, 1998; Lanphear et al., 2003; Nevin, 2000; Stretesky, 2003; Stretesky & Lynch, 2004). These areas also face the problems of broken families, inadequate prenatal health care, low rates of breast-feeding, and exposure to industrial pollution (Levitt, 1999). As such, high levels of lead exposure add an additional structural ill and obstacle for residents of disadvantaged communities, perhaps adding to higher levels of crime in these areas.

The ecological concentration of lead may also be incorporated into social learning and social control theories, as neighborhood variation in lead may influence the ratio of definitions favorable/unfavorable to crime (Sutherland, 1961) as well as the behaviors that are reinforced (Akers, 1977; Bandura, Ross, & Ross, 1961). For example, children with high lead body burdens may have siblings and friends who are from the same neighborhoods and who also have high lead body burdens. This may create a multiplicative effect of unacceptable behaviors (e.g., lack of attention to the requests of teachers), wherein lead-exposed children learn inappropriate behavior from similar children and peers through observation of their behavior. In addition, parents of children with high lead body burdens are likely to have been exposed to the same environmental risks when they were children, potentially affecting their parenting skills and decision-making capabilities. Indeed, delinquent peers, criminal siblings, and nonconventional parents all increase the risk of delinquent and criminal behaviors (Akers, 1977).

Finally, the lead literature is compatible with subcultural theories of crime, as differential lead exposure and treatment of the population segments may generate oppositional subcultures. Subcultural theorists hypothesize that economic and social disadvantage are conducive to the development of oppositional subcultures because the conditions cause residents to lose faith in the legal and political systems (Anderson, 1999). The unequal distribution of lead (Hird & Reese, 1998; Lanphear et al., 2003; Nevin, 2000; Stretesky, 2003) and the inadequacy of prevention and medical treatment for lead exposure in inner-city communities (Lanphear et al., 2003) may further feed this overall feeling of neglect and procedural injustice (Tyler, 2003). Taken together, the differential exposure to and treatment of lead provide yet another form of social disadvantage that may promote the criminogenic elements in resource-deprived minority communities.

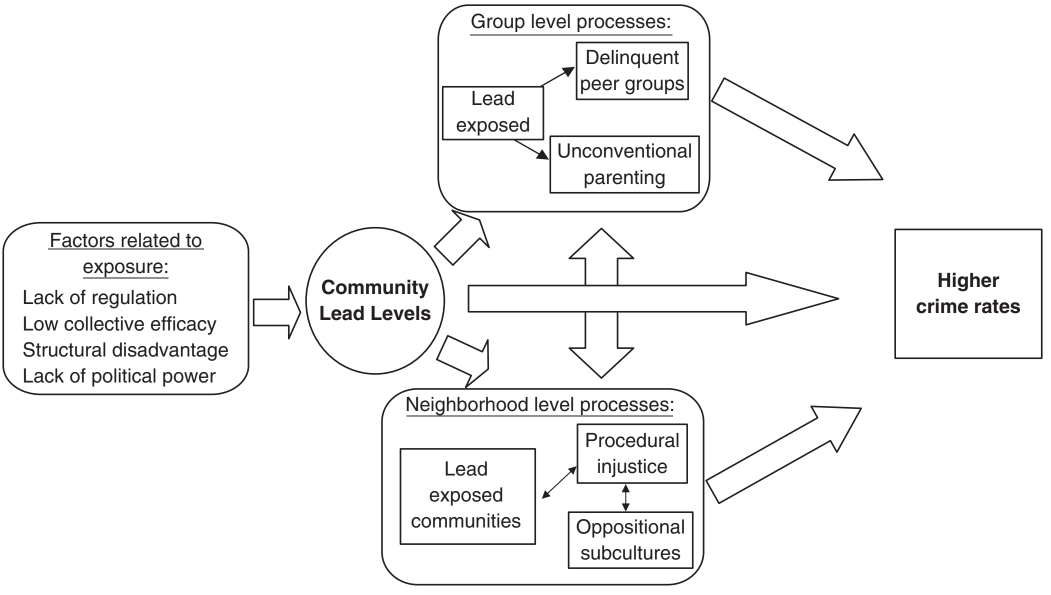

Figure 2: Community-Level Pathways of Lead Exposure to Higher Crime Rates

The distribution of lead. Social disorganization and other structural criminological theories can explain the uneven distribution of lead and its effect on crime (see Stretesky & Lynch, 2004). Regarding the former, social disorganization contributes to levels of collective efficacy, the willingness of residents to intervene in neighborhood problems, in geographic units (Sampson, Raudenbush, & Earls, 1997). Residents of areas with high social disorganization and thus low collective efficacy may not have the resources or the willingness to intervene to address lead emissions and exposures. Consequently, they may be exposed to lead at higher rates and concurrently not receive proper medical treatment.

An alternative explanation emerges from a consideration of green criminology. Green criminologists are largely concerned with definitions of environmental harm and environmental crime, the regulatory mechanisms and social control of environmental harm, and the relationship between criminalization and harm to the environment (White, 2008). Some green criminologists theorize that environmental harm and social injustice both result from race, gender, and class inequalities in society (Lynch & Stretesky, 2003). The correlation between lead exposure, race and class, and neighborhood structural disadvantage is consistent with this hypothesis and the broader environmental justice literature (see, e.g., Mohai & Saha, 2006, 2007). The practices of powerful individuals, groups, and institutions (e.g., corporations, regulatory agencies) may create disproportionate exposure by group and neighborhood. Companies may target disadvantaged communities for lead-related manufacturing due to a perceived lack of political resistance, inexpensive land, or deliberate racism/classism. In addition, inadequate regulation and enforcement of lead used in manufacturing processes may increase actual exposure in disadvantaged communities. Thus, integrating the lead literature with green criminology perspectives allows for a broader consideration of the players and social processes that may be responsible for differential lead exposure, impairment, and criminal activity.

In sum, the prior literature and our theoretical integration indicate that lead may be a distal predictor of crime and can promote crime in a variety of ways. In addition, patterns of lead exposure may be related to community social disorganization and/or structural processes driven by powerful groups. These observations have important implications for research. In the following section, the research implications of the lead-crime association are discussed.

IMPLICATIONS AND DIRECTIONS FOR FUTURE RESEARCH

THE LEAD AND CRIME RELATIONSHIP: INDIVIDUAL AND ECOLOGICAL LEVELS

There are some potential avenues for future criminological research. First, criminologists need to explore the varying methods used to establish the relationship between lead, delinquency, and crime. Most studies have measured aggression and delinquency using symptom counts of parent and teacher ratings like the Child Behavior Check List (Achenbach & Edelbrock, 1983). This measure has some limitations for establishing a link with delinquency, as many of the behaviors on the list are not delinquent acts. Future research should therefore explore the possibility of using clinical diagnostics in measuring aggression and delinquent acts.

Criminologists also need to examine the mechanisms by which lead affects criminal and delinquent behaviors. Extant literature on the individual-level lead exposure and crime relationship has not examined potential mediators for this relationship, even though studies show that the relationship between lead, crime, and delinquency is probably not a direct one. Lead exposure may result in risky behavior traits (i.e., ADHD and low IQ) that are conducive to criminogenic behaviors. For example, a person exposed to lead during childhood may develop externalized behavior problems, such as inattentiveness and hyperactivity. This externalized behavior may result in lack of concentration in school and poor grades, which in turn may lead to placement in special education classes and negative labeling on behalf of teachers. The labeling in school may result in an attenuation of the child's social bonds to prosocial institutions. Consequently, the child may join a delinquent subculture during adolescence and engage in crime during adulthood. These potential mechanisms demonstrate the significant gap between the time of lead exposure (i.e., independent variable) and the delinquency/crime (i.e., the dependent variable). Hence, life circumstances following lead exposure, such as family environment and socioeconomic status, must be explored in future studies to control for potential confounders of the association between lead and crime. This type of exploration will allow criminologists to more fully integrate the lead-crime association into broader theoretical frameworks.

The examination of disaggregated crime types is another avenue for future criminological research. Lead may not be conducive to all forms of crime. For example, lead exposure is most likely to produce crime types that result from loss of impulse control and poor decision making—namely, violent crime. Furthermore, impulsivity may produce specific types of violent crime, meaning the association between lead and crime would vary by the specific type of violent offense. Indeed, prior research documents differences in the covariates within violent crime types, specifically homicide (see Pizarro, 2008). Only a handful of studies (e.g., Pihl & Ervin, 1990; Stretesky & Lynch, 2004; and Wright et al., 2008) have begun to explore the relationship between lead and varying crime types. Criminologists should further disaggregate crime types in studies of lead to build on and test the generalizability of these studies at both the individual and the aggregate levels.

Aggregate-level studies can also be improved. Existing studies make an ecological fallacy in assuming that ecological lead levels are a reasonable proxy for individual lead exposure. Without demonstrating that environmental lead levels are directly related to the body lead burdens of the residents, aggregate studies may create systematic bias in the results (Stretesky & Lynch, 2001). In addition (as Stretesky & Lynch, 2001, acknowledged), counties that have higher air lead levels may also have higher crime rates, but the residents of those counties are not necessarily responsible for the crimes (Stretesky & Lynch, 2001). Finally, researchers also need to examine the relationship between lead exposure and crime rates in smaller geographical areas. County is the smallest unit of analysis used to date (Stretesky & Lynch, 2001, 2004). Although a useful first step, county-level analysis masks significant sociodemographic and crime variation within county. A county might include urban cities largely comprising economically deprived minorities and predominately Caucasian, low-poverty, suburban municipalities. Grouping these municipalities together as if they were one may result in aggregation bias if the relationship of interest is systematically different in different units within the county (Hammond, 1973).

Lead exposure prevention and lead reduction programs also need to be evaluated for crime reduction capacity. Lead reduction and regulatory programs have great potential for addressing the crime problem for several reasons. Lead exposure may spark a spiral of negative social consequences, meaning that intervention with lead-exposed children can prevent the more proximal criminogenic experiences. For example, children with a history of lead exposure may need additional assistance in school to avoid the negative consequences of poor school performance. Lead reduction programs may also have an immediate effect on crime depending on the mechanism through which lead leads to crime. Although reductions in crime due to decreases in cognitive dysfunctions may appear only over the long term, increases in legitimacy due to business regulation and lead reduction and treatment efforts may reduce crime (especially in disadvantaged communities) in the short run. Additional research may also support new policy initiatives by further fleshing out the lead-crime association to inform the creation of an efficient and effective intervention strategy.

THE DISTRIBUTION OF LEAD

Additional research on the distribution of lead is also necessary. Current research indicates that lead levels are higher in low socioeconomic and minority counties (Hird & Reese, 1998; Stretesky, 2003). Furthermore, Nevin (2000) argued that minorities and the lower class living in urban areas have a particularly high risk of exposure. If lead levels are indeed higher in disadvantaged communities when smaller geographical units are examined, this raises serious issues of environmental injustice (Bullard, Mohai, Saha, & Wright, 2007). Future research should examine the association between neighborhood demographics and lead levels within county to assess the need for environmental justice interventions.

These studies should also examine the source of neighborhood lead levels, whether the source of lead varies by community type (e.g., urban vs. rural), and whether different demographic groups are affected depending on the community location. For example, minority and lower class groups may have higher lead body burdens because they tend to reside in lower income and rental housing, which are more likely to have lead-based paint (Nevin, 2000; Lanphear et al., 2003). If urban lead poisoning is due primarily to the ingestion of lead paint chips, reducing industrial emissions may have little impact on lead poisoning or the associated cognitive and behavioral problems. Yet rural residents may have a higher risk of lead exposure from mining and smelter operations (Malcoe et al., 2002), requiring a different environmental justice intervention. In at least some regions of the country, poor Whites have a high risk of exposure to higher lead emissions from mining/smeltering operations in rural areas (Malcoe et al., 2002). To fully explore environmental justice considerations, the potential burden of all disadvantaged groups should be considered.[1]

Future research should explore the mechanisms through which differential lead burdens by community occur. Community social disorganization may result in little collective effort to address problems of lead emissions and exposure. However, green criminology perspectives suggest that a lack of social, political, and economic power may be responsible for the disproportionate location of environmental hazards in disadvantaged communities (Brooks & Rajiv, 1997). The distribution of lead emissions by businesses and the lack of lead removal in particular neighborhoods may operate through the same mechanisms. If this speculation is empirically valid, it suggests a need for external political support to facilitate lead prevention, reduction, and regulation programs in high-risk communities.

CONCLUSION

The lead and crime literature has substantial implications for criminological research. Researchers have shown a relationship between lead and delinquency/criminality (Denno, 1990; Dietrich et al., 2001; Masters et al., 1998; Needleman et al., 1996; Nevin, 2000; Pihl & Ervin, 1990; Reyes, 2007; Stretesky & Lynch, 2001, 2004; Wright et al., 2008). Multiple studies have also shown a relationship between lead and variables that have been documented to be associated with delinquency/crime, such as ADHD and IQ (e.g., Canfield et al., 2003; Dudek & Merecz, 1997; Schnaas et al., 2006, among the most recent). Despite this evidence, very few studies have approached the nexus of lead and crime from a criminological perspective (for exceptions, see McCall & Land, 2004; Stretesky & Lynch, 2001, 2004). Yet the empirical findings on the lead-crime association are compatible with traditional criminological theories. For example, the lead literature describes multiple mechanisms through which lead exposure may spiral into crime that are consistent with other theoretical work linking biological, psychological, and social factors to crime. In addition, the relationship between lead and criminality can be integrated into labeling theories of criminality and delinquency. Finally, differential exposure to lead and the treatments provided by the government to some sectors of the population are congruent with macro-level explanations of criminality, such as those that focus on the emergence of oppositional subcultures. The involvement of criminologists will build on the work of neurologists, toxicologists, and medical doctors to shed more theoretical insight on the nexus between lead and crime.

Empirical research also indicates that lead exposure disproportionately occurs in structurally disadvantaged communities. Social disorganization theory and green criminology offer testable hypotheses regarding the social processes that may underlie the disproportionate emissions and exposure. Once again, the involvement of criminologists in this line of research would further advance our understanding of the problem.

In addition to theoretical considerations, the lead and crime association has significant policy implications. Although public health interventions are not often thought of as crime reduction strategies, lead reduction is likely to increase public health and reduce crime. The acknowledgment and further exploration of lead reduction as a crime-fighting strategy can ultimately provide assistance to combat multiple social ills experienced in disadvantaged communities. Thus, it is imperative that criminologists from all theoretical perspectives recognize and/or engage in this area of research.

NOTE

1. Lanphear, Dietrich, and Berger (2003) also reported that children in affluent families who remodel older homes are at high risk of lead toxicity. Although we recognize the potential hazard to these children and do not downplay its significance, we do not discuss environmental justice interventions for this group because their potential exposure is not due to issues of structural disadvantage.

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