

Learning Outcomes among Students in Relation to West Virginia Coal Mining: an Environmental Riskscape Approach

Loretta R. Cain and Michael Hendryx

ABSTRACT

Children who live in coal mining areas are subject to environmental and socioeconomic risks for poor cognitive developmental outcomes. To assess the potential impact of the coal mining environmental riskscape on cognitive development in West Virginian children, we examined the associations between coal mining and learning outcomes among students in West Virginia public schools for the years 2005–2008. The study used a retrospective, natural field experiment design to test pass rates on standardized school performance tests in counties in West Virginia with and without coal mining activity. SUDAAN regression models controlled for a set of other risk variables on test performance. Proficiency rates for schools in coal-mining counties versus non-coal mining counties were significantly lower in all subject areas partly in relation to socioeconomic disadvantage, and remained significantly lower ($p < .0008$ or better) after adjusting for county high school education rates, percent of low-income students, percent of highly qualified teachers, number of students tested, and county smoking rates. Disparities in educational performance in mining areas reflect multiple environmental riskscape disadvantages. Adjusted differences in school test performance may reflect unmeasured confounds, environmental contaminants of the coal mining industry, or some combination thereof.

INTRODUCTION

COAL MINING AREAS of Appalachia are characterized by persistent levels of low educational attainment rates and high rates of poverty (Appalachian Region Economic Overview; Hendryx and Ahern, 2009; Hendryx, 2008; Hendryx, O'Donnell and Horn, 2008), and these conditions in turn relate to poor cognitive development in children (Huston and Bentley, 2010). Coal mining areas are also exposed to both air and water pollution from activities of the mining industry, which also may impair cognitive development. This combination of factors contributes to what Morello-Frosch and Shenassa (2006) referred to as stressors from the "environmental riskscape": the interactive and cumulative impacts of community and

individual-level variables on individual stress and on increased risk of negative health outcomes from environmental exposures.

Regarding environmental contributions, metals including arsenic, mercury, lead, cadmium, manganese, and others are present in coal strata (West Virginia Geologic and Economic Survey). Levels of ambient particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide, and nitrous oxides are elevated in areas proximate to coal extraction, processing, and transportation activities (Ghose, 2007; Ghose and Banerjee, 1996; Ghose and Majee, 2007). Higher blood cadmium levels have been documented in Turkish children living near coal mines, with mining waste a possible source (Yapici, 2006). Environmental data suggest that toxins from mining activity enter surface, underground, and ultimately potable water in coal mining areas (McAuley and Kozer, 2006; Palmer et al., 2010; Paybins et al., 2000; Stout and Papillo, 2004). Persons who live in coal mining areas of Appalachia are more likely than residents of other areas to rely on small public water systems or untreated well water (Hendryx and Zullig, 2009).

Ms. Cain is a doctoral student in the Department of Community Medicine at West Virginia University in Morgantown, West Virginia. Dr. Hendryx is Associate Professor, Department of Community Medicine, at West Virginia University.

Surface mining both as a percentage of total mining and in absolute production figures is increasing in the United States (Freme, 2008). Mountaintop removal mining is a form of surface mining that relies on the use of surface explosives and heavy machinery to remove rock and soil above the coal seams (Environmental Protection Agency, 2009); levels of dust are higher in surface mining versus underground mining operations (Ghose, 2007; Ghose and Majee, 2007). The rock and soil removed above the seams is dumped into adjacent valleys, burying mountain streams and negatively impacting surface water quality (Palmer et al, 2010).

After the coal is extracted, it is transported to processing sites where it is crushed and separated from noncombustible materials (EPA, 1995). This coal processing, which usually occurs near the mining sites, generates tons of localized dust and contaminates billions of gallons of water with toxic trace elements and chemical compounds used in the coal preparation process (Ghose, 2007; World Bank Group, 2009; Environmental Coalition and Coal River Mountain Watch). Compounds used in coal processing include various acrylamides, phthalates, benzenes, diesel fuels, and others that serve as flocculants, surfactants, and coagulants (World Bank Group, 2009; Environmental Coalition and Coal River Mountain Watch). Contaminated water, called slurry, is held in unlined surface impoundments or injected underground where interface with drinking water sources may occur. Cadmium, lead, arsenic, mercury, manganese, aluminum, and other toxic elements and compounds are present in coal, coal-processing activities, and coal waste (West Virginia Geologic and Economic Survey; World Bank Group, 2009; U.S. Geological Survey). Water quality is known to be impaired in mining versus non-mining areas of Appalachia with studies finding elevated levels of iron, manganese, aluminum, lead, arsenic, and other metals and compounds associated with mining (McAuley and Kozar, 2006; Palmer et al, 2010; Paybins et al, 2000; Stout and Papillo, 2004).

Environmental chemicals present currently or historically in coal, coal extraction, and coal processing—including phthalates, alkylphenols, polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins, bisphenol A, lead, mercury, zinc, aluminum, and cadmium—are known to impact cognitive development and function (Gladen et al, 1988; Jacobson and Jacobson, 1996; Koger, Schettler and Weiss (2005; Patandin et al, 1999; Schantz and Widholm, 2001; Zanchi et al, 2008). Three mechanistic explanations have been proposed for impaired cognitive development and learning capacity: (1) interference with the endocrine system (Schantz and Widholm, 2001; Bloom et al, 2009; Stefanidou, Maravelias, and Spiliopoulou, 2009); (2) impairment of the glutamate-nitric oxide-cGMP (cyclic guanosine monophosphate) pathway that influences learning ability (Liansol et al, 2009; Piedrafita et al, 2008); and (3) interference with the central nervous system (Stefanidou, Maravelias, and Spiliopoulou, 2009). Effects may occur from either prenatal or postnatal exposure.

Epidemiological studies suggest that exposure to urban air pollution is associated with immunodysregulation and systemic inflammation in children (Calderon-Garciduenas

et al, 2009). Other research proposes that significant adverse central and peripheral neurological effects are associated with lead exposure in young adults (Stokes et al, 1998) and that cognitive deficits associated with early environmental lead exposure is only partially reversed by a subsequent decline in blood lead level (Tong et al, 1998), suggesting some permanent damage to cognitive function. Trasande et al. (2005) found that between 316,588 and 637,233 children each year have cord blood mercury levels $>5.8 \mu\text{g/L}$, a level associated with loss of IQ. The resulting loss of intelligence persists over the lifetime for these children. Thatcher et al. (1982) found that higher levels of cadmium and lead in hair samples were related to lower intelligence test scores and school achievement in children ages 5 to 16.

Previous research has established higher mortality rates and higher rates of self-reported chronic illness among adults in coal mining areas that persist after statistical control for age, poverty, education, smoking, health insurance, and other covariates (Hendryx, O'Donnell and Horn, 2008; Hendryx and Zullig, 2009; Hendryx, 2009; Hendryx and Ahern, 2009), suggesting that environmental impacts of the coal mining industry negatively affect health. Research has also documented higher rates of low birth weight infants among mothers in coal mining areas after control for other risks (Ahern et al, 2010).

Because of (1) established socioeconomic disadvantages and (2) potential water and air pollution exposures resulting from coal mining and processing in West Virginia, and the potential impact of these activities on cognitive development in children, we examined the association between coal mining activity and learning outcomes among students in West Virginia schools for the years 2005–2008. First, we examined the association between mining activity and environmental riskscape stressors that may impair learning performance. Then, we controlled for this set of risk factors to test an ecological hypothesis that environmental exposures from mining may impair children's cognitive development.

METHODS

Design

The study employs a retrospective, natural field experiment design to test pass rates on standardized school performance tests in counties in West Virginia with and without coal mining. Data cover test scores for four academic years, 2004–05 through 2007–08. Analyses examine pass rates before and after statistical control for covariates, and examine pass rate variability across subject, grades, and time.

Data

Dependent variables. The dependent variables are the percentages of students in each school and grade who passed standardized tests in four subject areas: mathematics, social studies, reading, and science. School proficiency percentages were obtained for every regular public

school, grades 3–8 and grade 10 listed in the West Virginia Department of Education assessment database between 2005–2008, found at <<http://wveis.k12.wv.us/nclb/pub/>>. Special education schools and vocational schools are not included. These standardized tests are not administered in other K–12 grades.

Proficiency results are determined by the West Virginia Educational Standards Test (WESTEST). This standardized test was designed by the West Virginia Department of Education in collaboration with CTB-McGraw Hill, which serves as the test vendor. The individual content assessments measure student performance in reading/English, mathematics, social studies (10th graders do not take the social studies test) and science, based on test questions that were aligned to the West Virginia Department of Education Content, Standards and Objectives (CSOs), the state's formal learning guidelines and criteria. The assessment consists of a combination of essay, short answer, and multiple choice questions. Testing typically occurs over a period of four school days. Results are used for internal quality improvement efforts and in part to meet federal No Child Left Behind accountability standards. Further information regarding test development and validation may be found at <http://wvde.state.wv.us/oaa/westest2_sitemap.html>.

Independent variable. We obtained coal production data from the Energy Information Administration (EIA) (Freme, 2008) measured as tons of coal mined in every county each year for the years 2004–2007, covering the period of time for the school performance data up to the most recent production year available at the time of the study. A dummy variable was created to identify counties with any amount of coal mining (yes or no) over these years. In most cases, counties that mined coal in one year did so in most or all years, and in years prior to the study, due simply to the presence of economically minable coal in the county.

Covariates. We obtained data on county-level high school education rates from the 2005 Area Resource File (ARF) (Area Resource File, 2006), which in turn was drawn from the 2000 U.S. Census. This variable was included as a covariate to reflect general educational performance of the population.

Smoking might reflect an important environmental exposure as well as a proxy socioeconomic measure. County smoking rates were obtained from Behavioral Risk Factor Surveillance System (BRFSS) (2007) survey results reported by the West Virginia Bureau of Public Health from a 2003 survey.

From the school test score dataset we examined six potential covariates and used four in final models. The four that were used in final models included grade level, the percent of the school's students who were eligible for free or reduced lunch programs as an indicator of student socioeconomic status, the number of students tested in each subject area as an indicator of school size, and the percent of classes taught at each school by teachers who were not "highly qualified" as rated by the state Depart-

ment of Education. The "highly qualified" designation is based on federal No Child Left Behind standards; teachers must meet state certification requirements and demonstrate subject competency through testing, advanced credentials, academic major, or performance evaluation. Regarding grade level, we collapsed grades into four groups: third/fourth, fifth/sixth, seventh/eighth, and tenth, to increase the number of observations in each group. We also explored the use of average class size under the assumption that smaller classes might have better pass rates, but found the reverse to be the case; we dropped the variable from the models but its inclusion or exclusion had no significant impact on the effect of the coal mining variable. We also examined total school enrollment but it was correlated highly with number of students tested so only the latter variable was included in final models.

Analysis

Descriptive statistics were calculated for all study variables, following by inferential analyses to examine school test pass rates in both unadjusted and adjusted models. Unadjusted and adjusted models used SUDAAN Proc Regress to account for the nested sampling structure of schools within counties to compare pass rates in mining versus non-mining counties for each subject area collapsed across years. The unit of analysis is the school-grade. Adjusted models controlled for the effects of number of students tested in the subject area, percent low-income students, the percent of classes taught by teachers who were not highly qualified, the county-level population high school education rate, county smoking rate, and grade.

RESULTS

A total of 646 schools were included in the database. At the grade level, there were a total of 1,840 observations (school × grade) with school performance data. However, missing data on the percent of students with low income reduced the final sample to 1,812 observations.

Descriptive findings

Table 1 summarizes pass rates by grade and subject. Pass rates were generally highest for science and lowest for social studies. Pass rates tended to decline in the higher grades. Although not shown on the table, pass rates for all subjects increased approximately 1%–2% over the years studied from earliest school year to latest school year.

Risks in mining and non-mining counties

Table 2 shows a comparison of covariates in mining and non-mining counties. T-tests between groups used a Satterthwaite correction for unequal variances. Coal-mining areas were characterized by significant socioeconomic and behavioral disadvantages: they had higher percentages of low-income students, lower population

TABLE 1. PASS RATES BY SUBJECT AND GRADE FOR FULL SAMPLE, WEST VIRGINIA SCHOOLS 2004–2008

Grade	Math		Reading		Science		Social Studies	
	N	Pass Rate	N	Pass Rate	N	Pass Rate	N	Pass Rate
3	404	77.9	404	78.9	404	87.1	404	79.0
4	401	78.0	401	82.0	401	85.0	401	78.5
5	365	79.7	365	79.2	365	85.1	365	77.7
6	192	76.2	192	81.3	192	84.6	192	73.0
7	166	75.4	166	81.3	166	82.3	166	70.0
8	167	71.6	167	80.6	167	84.0	167	70.4
10	117	67.2	117	74.7	117	85.7	–	–
Total	1812	76.4	1812	80.0	1812	85.2	1695	76.2

high school education rates, and higher population smoking rates. Schools in mining areas were also characterized by lower enrollments, fewer tested students in each subject area, and higher rates of classes taught by teachers not highly qualified, but were not different from schools in non-mining counties on average class size.

Model results: unadjusted and adjusted

Differences in pass rates between coal mining and non-mining counties before adjusting for covariates are summarized in Table 3. Schools in coal-mining locations had significantly lower pass rates for all subject areas.

Differences in pass rates after adjusting for covariates are summarized in Table 4. Model fit was significant at $p < .0001$ for all models using adjusted Wald F tests. Although not shown in Table 4, one or more covariates were significantly related to pass rates in all models; variables such as lower smoking rates, higher high school education rates, higher socioeconomic status (SES) student bodies, and higher rates of qualified teachers were related to higher pass rates. The differences in pass rates between mining and non-mining locations, although reduced relative to Table 3 after accounting for other risks, remained significant in favor of the non-mining locations.

Although the differences in pass rates may seem small, when extrapolated to the number of impacted students

the magnitude of the effects becomes more apparent. There were on average 157,633 students per year enrolled in schools in the coal mining counties. A difference in pass rates of 1% means that 1,576 additional students failed one or more tests each year after controlling for covariates. An unadjusted difference of 3% that includes socioeconomic disparities in mining counties translates to 4,729 additional students who failed one or more tests each year.

DISCUSSION

Water and air pollution problems resulting from coal mining activity have been well established (Ghose, 2007; Ghose and Banerjee, 1995; Ghose and Majee, 2007; Yapici, 2006; McAuley and Kozar, 2006; Palmer et al, 2010; Stout and Papillo, 2004; Hitt and Hendryx, 2009). Known pollutants present in coal, and in coal extraction, transportation, and processing activities include arsenic, mercury, lead, cadmium, aluminum, manganese, PM_{10} and $PM_{2.5}$, polycyclic aromatic hydrocarbons, phthalates, acrylamides, benzenes, and others. Children exposed to pollution from these activities might experience impaired cognitive development resulting in poorer learning outcomes compared to children in non-mining areas. Our results showed significantly impaired learning outcomes in all

TABLE 2. COMPARISON OF RISK VARIABLES BETWEEN COAL MINING AND NON-MINING LOCATIONS

	Coal Mining Counties		Non-Coal Mining Counties		P <
	N	Mean	N	Mean	
Percent low income students	1158	57.2	654	51.3	.0001
High school education rates	1158	72.6	654	77.0	.0001
Smoking rates	1158	28.2	654	26.8	.0001
Average math students tested	1158	67.7	654	83.8	.0001
Average reading students tested	1158	67.7	654	83.8	.0001
Average science students tested	1158	66.6	654	82.6	.0001
Average social studies students tested	1083	60.7	612	75.6	.0001
Total enrollment	1083	354.4	612	407.8	.0001
Average class size	1083	19.7	612	19.7	.72
Percent classes taught by teachers not highly qualified	1158	5.8	654	4.3	.0002

TABLE 3. UNADJUSTED PASS RATES BEFORE CONTROL FOR COVARIATES COLLAPSED ACROSS YEARS AND GRADES, BETWEEN SCHOOLS IN WEST VIRGINIA WITH AND WITHOUT COAL MINING 2004–2008

Pass rate by subject	Mean Pass Rate (SE)		P <
	Coal Mining Counties	Non-Coal Mining Counties	
Mathematics	75.44 (.24)	78.31 (.30)	.0001
Reading	79.23 (.19)	81.57 (.24)	.0001
Science	83.95 (.18)	87.38 (.21)	.0001
Social Studies	74.87 (.27)	78.74 (.32)	.0001

SE = standard error.

subject areas among students in coal mining counties versus non-coal mining counties in West Virginia.

Results also showed that children in coal mining counties in the state experience disadvantages across the environmental riskscape. They are more likely to have teachers who do not meet state criteria for highest quality, and are more likely to live in low-income households, to grow up in environments where smoking takes place, and to have more adults in their environments without a high school education. These stressors may lead to increased vulnerability to environmental exposures (Morello-Frosch and Shenassa, 2006; Gee and Payne-Sturges, 2004). The combination of these disadvantages may contribute to poorer educational performance and to poorer health outcomes during developmental periods (Huston and Bentley, 2010; Ahern et al, 2010; Lewis et al, 1992) and later as adults (Hendryx and Ahern, 2009; Hendryx, 2008).

The results add to a growing body of knowledge that coal mining activity in Appalachia is linked to a set of serious, negative health and developmental consequences. Rates of low birth weight deliveries are elevated in Appalachian mining areas (Ahern et al, 2010). Excess age-adjusted deaths in coal mining areas have been estimated to be as high as 10,923 lives per year (Hendryx and Ahern, 2009). Additional research indicates that mortality rates in Appalachian counties with the highest levels of coal mining were significantly higher relative to non-mining areas for chronic heart disease, respiratory disease, kidney disease, and lung cancer (Hendryx, O'Donnell and Horn, 2008; Hendryx, 2009). Research also shows that Appalachian residents reported significantly higher risk of cardiovascular, respiratory, and kidney

disease morbidity (Hendryx and Zullig, 2009; Hendryx and Ahern, 2009).

Limitations of the study include the ecological and cross-sectional design. The timing, magnitude, route, and duration of potential exposures for individual students are unknown. What specific agent(s) may be responsible for observed effects are unknown; Lewis et al. (1992) suggested that prenatal exposure to a combination of metals, rather than exposure to a single source, may serve to impair child cognitive development. Huston and Bentley (2010) argue that child development is based on cumulative and interacting factors across a variety of social, economic, behavioral, and environmental fields.

In addition, the measurement of confounds is imperfect, and there may be other unmeasured variables that at least partially account for observed differences in test performance. We attempted to account for factors such as low income, class size, teacher quality, and county high school graduation rates, which all influenced test performance, but as in any study design such as this, additional unmeasured factors unique to mining areas may be present.

CONCLUSION

Further research is needed to investigate directly the impact of pollution from coal mining and coal processing on cognitive function and learning outcomes in children, in the context of the entire environmental riskscape. If confirmed, the results point to the need for better environmental monitoring and control, and for the need to develop alternative economic models for mining areas. Coal mining carries significant environmental, health,

TABLE 4. LEAST SQUARE MEANS ADJUSTED PASS RATES FOR 2004–2008,^a COLLAPSED ACROSS YEARS AND GRADES, BETWEEN SCHOOLS IN WEST VIRGINIA WITH AND WITHOUT COAL MINING

Pass rate by subject	Mean Adjusted Pass Rate (SE)		P <
	Coal Mining Counties	Non-Coal Mining Counties	
Mathematics	75.93 (.21)	77.24 (.29)	.0001
Reading	79.69 (.17)	80.60 (.23)	.0008
Science	84.48 (.15)	86.35 (.20)	.0001
Social Studies	75.68 (.21)	77.15 (.28)	.0001

^aCovariates include grade level, average number of students tested in the matching subject area, percent of classes in the school taught by teachers who were not highly qualified, county high school education rate, county smoking rate, and percent of the school's students who were low income.

SE = standard error.

social, and economic costs that should be factored into the cost of coal (Hendryx and Ahern, 2009) and should be considered in choosing the best economic development programs for mining areas to pursue. This will be especially important as recoverable coal reserves enter permanent decline and become smaller parts of local economies, which is happening now in many parts of the Appalachian region (Ruppert, 2001). Greater investment in public education in the Appalachian coalfields is also indicated to counter the negative educational performance there, whether the causes are socioeconomic or environmental in nature, and to assist the populations who live there in transition to more health-promoting economic alternatives.

DISCLOSURES

The authors have no conflicts of interest or financial ties to disclose.

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Address correspondence to:

Michael Hendryx

Department of Community Medicine

West Virginia University

One Medical Center Drive

PO Box 9190

Morgantown, WV 26506

E-mail: mhendryx@hsc.wvu.edu