

The Association of Parent-Reported Lead Exposure with Language Skills and Externalizing Behavioral Problems in Children

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Abstract

An impressive amount of research has begun to suggest that language deficits and externalizing behavioral problems in children are closely connected. To this point, however, little research has been aimed at examining potential risk factors that might disrupt both the development of behavior and the acquisition of language in early childhood. Findings from empirical-based studies have consistently indicated that lead exposure is a risk factor for myriad negative outcomes in children. We build off this literature and examine the effects of lead exposure on both language development and externalizing problem behaviors. The current study analyzes data drawn from the Fragile Families and Child Wellbeing Study in order to investigate the effects of parentally reported lead exposure on verbal intelligence and externalizing problems in children. Our findings suggest that the development of externalizing problems and language deficits appear to share a common pathway which may be vulnerable to the deleterious influence of lead exposure.

Keywords: Exposure to lead; Behavioral problems; Chronic; Language skills

Introduction

In the pantheon of developmental achievements in the life course of a human, the acquisition of language ranks high in terms of importance for future life successes [1,2]. The use of language represents a foundational component of human social life and it enables children (and adults) to more efficiently navigate social interactions; especially within their peer groups [1]. As Ridley [3] points out, moreover, the capacity for language is a fundamental aspect of human nature and a critical component of normal growth and development. What this necessarily means is that as a child's capacity for language develops so too does their ability to interact in effective and prosocial ways with other children and adults [1,3].

Perhaps not surprisingly, and as numerous scholars have previously pointed out, delayed language development correlates quite consistently with a litany of adversities [1,2,4-6]. Research, for example, has revealed that children with lower language abilities are less adept at regulating impulsive tendencies compared with children who score higher on measures of language skills [2]. Evidence concerning the comorbidity of language and conduct problems suggests that well over half of preschool aged children who exhibit delays in language skills also display signs of increased conduct problems [7]. Alternatively, roughly 70 percent of children who are clinically diagnosed as having an externalizing behavioral disorder also display significant language deficits [4].

That there is an association between language skills and behavioral problems appears to be relatively accepted by behavioral scholars [2]. What remains less certain, however, is the exact reason why language and behavioral development mirror each other so closely. One possibility is that the two outcomes develop along a similar pathway. Known as a shared etiological hypothesis, this explanation suggests that language skills and antisocial behavior share, at least in part, a developmental origin [1,2]. Furthermore, what this line of reasoning implies is that the same risk factors shown to influence behavioral problems should also impact language development.

Beaver et al. [2] examined whether a shared etiological hypothesis

might account for the covariation between language ability and self-regulation in early childhood. The results of their analysis revealed that between 61 and 76 percent of the covariance in language ability and self-regulation was due to overlapping genetic influences. A very similar pattern of findings emerged for the overlap of language abilities, antisocial behavior, and negative peer interactions [1]. Of equal importance, however, was the finding that environmental influences were also implicated in the co-development of language skills and behavioral regulation [2]. In light of these findings, the question of which specific environmental risk factors disrupt language and behavioral development bears addressing. One possible risk factor is prenatal and postnatal exposure to lead. The neurotoxic properties of lead have been shown to adversely impact a wide range of developmental domains in children, including language and behavioral outcomes [8,9]. Despite a wealth of prior research, there has been no empirical effort (to which we are aware) aimed at determining whether lead concurrently impacts language skills and antisocial behavior.

Lead Exposure, Behavioral Problems and Language Development

Evidence concerning the negative impact of lead on behavioral outcomes has been consistently replicated in both animal and human subjects. Chronic lead exposure, for example, has been found to drastically increase level of hyperactivity observed in mice [10]. Similarly, lead exposure has been shown to increase attention deficits, hyperactivity, social withdrawal, and aggression in children [9,11]. Sciarillo et al. [9] analyzed a sample of approximately 200 children

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between the ages of 2 and 5 years and reported that as exposure to lead increased so too did levels of both internalizing and externalizing behavioral problems.

Existing research has also examined whether lead exposure increases the risk of aggressive and delinquent behaviors [12]. Needleman et al. [13], for example, provided evidence that increases in bone lead concentrations were associated with a range of maladaptive behaviors in early adolescence including juvenile delinquency and aggression. Wright and colleagues [14] analyzed data drawn from the Cincinnati Lead Study in order to estimate whether lead exposure early in life corresponded to criminogenic outcomes at later points in development. After controlling for potential confounders, the results of the study revealed that lead exposure in childhood was related to total and violent arrests once the participants had reached early adulthood.

In comparison to the amount of research concerning the effects of lead on behavior, there has been relatively little attention devoted to determining whether lead exposure negatively affects the acquisition of language. We are aware of at least four studies that have directly examined the association between exposure to lead and language development. First, Ernhart and Greene [15] analyzed a sample of over 300 children evaluated for language skills at the ages of 1, 2, and 3 years. The results of the study provided little evidence that lead was related to language skills in early childhood. Second, Campbell et al. [16] analyzed a randomly generated sample of boys between the ages of 11 and 14 years old. Lead exposure was assessed using X-rays in order to directly measure bone lead concentrations in the tibia. The results of the study demonstrated that children with the highest bone lead levels scored lowest on measures assessing language processing performance. In the third study, Yuan et al. [17] analyzed functional magnetic resonance imaging (fMRI) scans taken while subjects in the study performed a verb generation task. The results suggested that activation in areas of the brain linked to language (e.g., Broca's area) were diminished in subjects exposed to higher levels of lead. Finally, Hubbs-Tait et al. [18] examined the relationship between lead exposure and verbal functioning in children. These researchers assessed exposure to lead by examining blood samples collected from the participants. Verbal skills were measured using the Peabody Picture Vocabulary Test-III (PPVT-III) and the findings revealed some evidence that lead disrupted cognitive development, yet the relationship between lead and PPVT-III scores failed to reach statistical significance.

Ultimately, a strong body of evidence suggests that lead exposure increases the risk of externalizing behavior problems in children. A growing number of scholars have also investigated the potential link between lead exposure and language development. The findings gleaned from this line of research are less conclusive with some studies reporting an association [16,17] and others not [15,18]. It is important to point out, however, that none of the prior research into the influence of lead on verbal development considered the possibility that biological sex may be a moderating factor. This is one area in which the current study will expand on the extant knowledge base.

The Current Study

The purpose of the current study is twofold. First, we directly estimate the association between lead exposure and externalizing behavior problems and between lead exposure and language skills. Given the covariation between language skills and behavioral problems, we hypothesize that lead exposure represents a risk factor for the development of both language and externalizing problem behaviors in children. Second, we examine whether the effects of lead are moderated

by gender. Previous research has provided some empirical evidence to suggest that males and females may be differentially impacted by the toxic properties of lead [8]. To our knowledge, the current study represents the first attempt to test for interactions between gender and lead on the development of both behavioral problems and language acquisition in early childhood.

Methods

Sample

In order to explore the interconnections of lead exposure with language and behavioral development, the current study examined data drawn from the Fragile Families and Child Wellbeing Study (FFCWS) [19]. The FFCWS [19], represents a large sample of families living in the United States. Data collection followed a sequence of steps which began with drawing a random sample of U.S. cities, followed next by hospitals located within the cities. New mothers (those who had recently given birth) were approached by research staff and recruited for participation in the initial round of data collection. This phase of the study produced a total sample of approximately 5,000 mothers and children (fathers, when available, were also included in the sample) [19]. The racial/ethnic breakdown of the FFCWS sample was as follows: Black/non-Hispanic (69%), White/non-Hispanic (8%), Hispanic (19%), and other (4%) [19].

In order to isolate the effects of lead on child development we employ the first three waves of data available in the FFCWS. Wave 1 data collection (which occurred between 1998 and 2000) included a wide variety of questions regarding the family composition, employment status, and personality traits of the participants [19]. Wave 2 of the FFCWS was collected approximately one year later and included a very similar battery of questions. For the third wave of data collection (Wave 3) mothers and fathers were administered telephone based surveys (very similar to those at prior waves). An in-home survey with the child's primary caregiver (generally the child's biological mother) also took place when the child was approximately three years old.

Measures

Externalizing behavioral problems

During the in-home interviews conducted with the primary caregiver (usually the biological mother at Wave 3), respondents were asked to report about the child's behavioral tendencies. The questions were designed to assess behavioral and conduct problems as well as difficulties in self-regulation and impulse control in the child which often manifest early in the life course and were drawn from standardized behavioral inventories such as the child behavior checklist (i.e., the CBCL; see Achenbach and Edelbrock [20] for full descriptions of the measures). The parental respondents were asked a range of questions designed to measure the child's behavioral tendencies. We further examined the individual items and the results suggested that thirty-two of the questions loaded together on the same variable. Following the lead of prior researchers [21] we summed each of the items in order to create the Wave 3 externalizing problem behavior scale. An appendix containing all of the individual items is presented in Appendix A.

Receptive vocabulary skills

In order to gauge variation in the development of vocabulary skills the focal children in the study were administered the Peabody Picture Vocabulary Test (PPVT). The PPVT is a widely used instrument among cognitive and developmental psychologists and was designed

| | Min | Max | Mean | S.D. |
|-----------------------------------|-----|-----|-------|-------|
| <i>Child Measures</i> | | | | |
| Externalizing Behavioral Problems | 0 | 59 | 18.92 | 10.67 |
| Receptive Vocabulary Skills | 40 | 137 | 85.74 | 16.66 |
| Lead Exposure | 1 | 3 | 1.09 | 0.34 |
| Gender | 0 | 1 | 0.52 | 0.50 |
| <i>MATERNAL MEASURES</i> | | | | |
| Maternal Education | 1 | 9 | 4.63 | 1.82 |
| Age at Child's Birth | 15 | 43 | 25.28 | 6.04 |
| Race | 0 | 1 | 0.48 | 0.50 |

Table 1: Descriptive Statistics.

to measure the acquisition of language abilities beginning very early in the life course [22,23]. For the current analysis, scores on the PPVT (collected during the third wave) were examined and left coded such that higher scores corresponded to higher levels of verbal intelligence.

Lead exposure

Mothers in the FFCWS were asked a series of interlocking questions in order to assess their child's exposure to lead during the Wave 3 in-home interviews. First, participants were asked whether their child had been tested for lead poisoning. Second, if the participant responded affirmatively, they were asked to report the results of the lead testing; responses were coded so that 1=normal exposure (n=1,671; 93%), 2=lead exposure that failed to require medical treatment (n=87; 5%), and 3=lead exposure in amounts sufficient as to require medical treatment (n=35; 2%)¹. Respondents who indicated that the child had not been tested for lead poisoning were coded as missing on the variable.

Maternal education

During the first round of interviewing mothers were asked to report their highest level of education. The responses to this item ranged from 1 (no formal education) to 9 (graduate level education).

Maternal age at birth

We included a measure of maternal age—assessed during the first wave of interviews—as a continuous measure in the current study.

Maternal race

Maternal race was included as a covariate in order to account for potential confounding influences. The item was coded such that 0=non-Black and 1=Black.

Child gender

The child's gender was assessed during the Wave 1 interviews and coded so that 0=female and 1=male.

Plan of Analysis

The first step in the plan of analysis involved estimating the

¹ Percentages in each group represent rounded estimates.

² We conducted additional sensitivity analyses in order to determine whether the inclusion of a measure of maternal intelligence (in this case, both the mother's PPVT score, as well as the mother's score on the Wechsler Adult Intelligence Scale) would substantively alter our findings. The results, not presented but available, generally suggested that our original findings remained intact, despite the inclusion of other covariates. It is worth noting, though, that the inclusion of the maternal PPVT scores diminished the interaction effect to non-significance in the model predicting externalizing problems.

effect of lead exposure on externalizing behavioral problems using the full sample of participants. To do so, the measure assessing lead exposure, along with each of the maternal measures, was entered into an ordinary least squares (OLS) regression equation. Step two involved testing whether the effects of lead exposure were moderated by the child's gender. In order to test for moderating effects, we introduced a multiplicative interaction term into the OLS equations along with each of the other covariates. Step three was included to examine the influence of lead exposure on the development of language skills. Similar to step one, lead exposure, as well as the maternal measures, was entered into an OLS regression equation, however, for step three the outcome measure was a measure of receptive vocabulary. Step four was intended to examine whether the child's gender moderated the effect of lead exposure on receptive vocabulary. Once again, a multiplicative interaction term was included in the OLS equation in order to test for a gender X lead interaction. In the fifth, and final, step we analyzed split samples (i.e., a male sample and female sample) in order to further isolate the effects of lead on behavioral problems and language. We calculated regression models for both males and females using all of the control variables described above (excluding the measure of gender) (Table 1).

Results

Table 2 presents the findings from the OLS regression equations included to examine the effects of lead exposure on externalizing behavioral problems. The results contained in Model 1 reveal that lead exposure had a significant effect on behavioral problems even after controlling for the influence of possible confounding factors. In order to determine whether the effects of lead exposure were moderated by gender, we included a multiplicative interaction term in Model 2 of Table 2. The results of the second model provided evidence that the effects of lead interacted with gender in order to predict increased externalizing problems in three year old children. The interaction term was positive, meaning that males were more affected by lead exposure in terms of their behavioral problems. Put another way, the positive correlation between lead exposure and behavioral problems was significantly stronger for males, as compared to females.

| | Model 1 | | Model 2 | |
|-----------------------|---------------|-----------|---------------|-----------|
| | <i>b/Beta</i> | <i>SE</i> | <i>b/Beta</i> | <i>SE</i> |
| Lead Exposure | 2.73/.09* | .79 | .65/.02 | 1.15 |
| Maternal Education | -.65/-.10* | .18 | -.65/-.10* | .18 |
| Maternal Age at Birth | -.18/-.09* | .05 | -.18/-.09* | .05 |
| Maternal Race | -.61/-.03 | .57 | -.64/-.03 | .57 |
| Gender | 2.34/.11* | .54 | -1.86/-.09 | 1.79 |
| Gender X Lead | --- | | 3.87/.21* | 1.57 |

*Significant at the .05-level, two-tailed

Table 2: OLS Regression Models Predicting Externalizing Problem Behaviors.

Table 3, presented below, contains the results of regression

| | Model 1 | | Model 2 | |
|-----------------------|---------------|-----------|-------------------------|-----------|
| | <i>b/Beta</i> | <i>SE</i> | <i>b/Beta</i> | <i>SE</i> |
| Lead Exposure | -.79/-.02 | 1.21 | 1.89/.04 | 1.83 |
| Maternal Education | 2.41/.23* | .29 | 2.40/.23* | .29 |
| Maternal Age at Birth | -.01/-.00 | .08 | -.01/-.00 | .08 |
| Maternal Race | -3.71/-.11* | .91 | -3.69/-.11* | .91 |
| Gender | -1.89/-.06* | .84 | 3.24/.10 | 2.77 |
| Gender X Lead | --- | | -4.71/-.18 ^a | 2.42 |

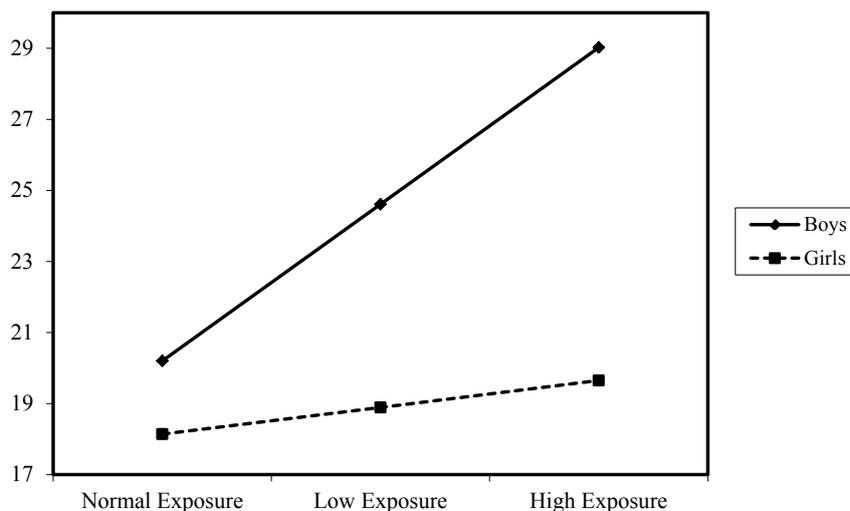
*Significant at the .05-level, two-tailed; ^aSignificant at the .052 level, two-tailed.

Table 3: OLS Regression Models Predicting Receptive Vocabulary Skills.

analyses designed to estimate the effects of lead exposure on language ability (i.e., the PPVT scores)². The findings in Model 1 revealed that lead exposure did not have a significant main effect on language skills. Inspection of Model 2, however, revealed that gender moderated the effect of lead exposure on language development. In this case, exposure to lead significantly decreased scores on the language skills measure, but the effect was conditioned by the sex of the respondent.

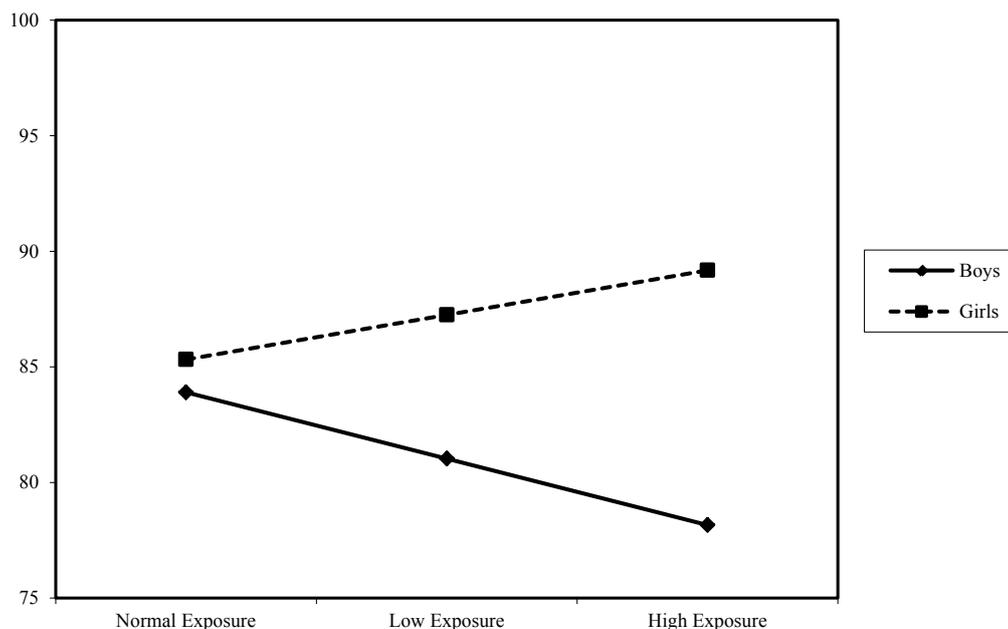
As a final step in the analysis, we plotted predicted scores for

both the externalizing behavioral problems measure and the language skills scale based on lead exposure status. The predicted values were calculated separately for both males and females since an interaction effect was detected in the OLS models using a multiplicative interaction term. The graphs are presented in Figures 1 and 2. As illustrated in Figure 1, there was a steep increase in behavioral problems for males as lead exposure increased. We transition next to examining the effects of lead on language skills which are presented in Figure 2. The findings



Note: Predicted values estimated with all other variables set to their means;
 Lead exposure for boys: $b=4.41$, $SE=1.11$, $Beta=.14$, $p<.05$; Lead exposure for girls: $b=.75$, $SE=1.12$, $Beta=.02$, $p>.05$
 Models included controls for maternal race, education, and age when child was born.

Figure 1: Predicted Values on the Externalizing Behavioral Problems Scale across Different Levels of Lead Exposure for Boys and Girls.



Note: Predicted values estimated with all other variables set to their means;
 Lead exposure for boys: $b=-2.87$, $SE=1.67$, $Beta=-.06$, $p=.087$; Lead exposure for girls: $b=1.93$, $SE=1.76$, $Beta=.04$, $p>.05$
 Models included controls for maternal race, education, and age when child was born.

Figure 2: Predicted Values on the Receptive Vocabulary Skills across Different Levels of Lead Exposure for Boys and Girls.

revealed that for males in the sample, there was a noticeable decline in language skills as a function of lead exposure³. For females, however, the influence of lead on language ability failed to reach statistical significance.

Discussion

Decades of empirical research have demonstrated that exposure to lead constitutes a significant threat to child development [11, 14,24-26]. Lead exposure has been shown to disrupt formation and functioning in the central nervous system, adversely impact the growth dendrites, decrease language ability, and increase the risk of certain childhood medical conditions such as encephalopathy [9,16,25]. Exposure to lead has also been linked to host of neuropsychological deficits, not the least of which involve attention problems and diminished memory and learning ability [26]. The deleterious health ramifications stemming from chronic lead exposure include an elevated risk for renal failure, hypertension, and even death (resulting from cardiovascular disease and cancer) [25,27]. In short, there is little (to no) debate among researchers that lead represents a major threat to the general health and wellbeing of both children and adults.

The goal of the current study was to examine the influence of lead on both receptive vocabulary and externalizing behavioral problems in children. To our knowledge, this was one of the first attempts to concurrently test whether lead exposure is associated with the development of both behavioral problems and receptive vocabulary skills. The results of our study revealed two broad findings. First, lead exposure was found to be a risk factor for the development of behavioral problems. Second, and perhaps most importantly, the adverse effects of lead on both language skills and externalizing behavioral problems were moderated by gender. More specifically, exposure to lead in males resulted in significantly lower levels of receptive vocabulary and increased behavioral problems.

These findings are not surprising given the evidence linking lead to behavioral problems, as well as the significant covariation of language skills and externalizing problems detected by previous researchers [2]. The results of this study are in line with a growing body of research suggesting that males, in general, are more vulnerable to teratogens than are females [28]. Furthermore, the results of the current study indicate that receptive vocabulary skills and behavioral problems may share a similar etiological pathway [2]. What this necessarily means is that disruptions in the development of behavior may also manifest as delays in the acquisition of language and vice versa.

The analyses were not without limitations. First, the current study was not capable of identifying the exact mechanisms by which lead exposure results in diminished vocabulary skills or behavioral problems in males. Second, the FFCWS is not a nationally representative sample. Children in the sample were more likely to have been raised in socially disadvantaged households by a single minority parent. This becomes potentially important considering that prior research has demonstrated that individuals scoring lower on measures of socioeconomic status are more likely, on average, to report higher overall blood-lead levels [8]. Because the FFCWS was skewed towards lower levels of socioeconomic status it is possible that some of the participants were

disproportionately exposed to lead. In other words, the extent to which the findings reported here would extend to another population remains an unresolved empirical issue.

A third, and arguably the most important, limitation concerns the measurement of lead exposure. Lead exposure was assessed by asking the parents (primarily the mothers) in the sample whether their child had ever been tested for lead poisoning, and if so, whether the results indicated that medical attention was warranted. In most instances, it would be preferable to include more direct measures of lead exposure such as circulating blood-lead levels extracted from a sample of blood taken from the participant. Unfortunately, we were not able to include such measures in the current study. Given that the FFCWS is a high-risk sample, however, it may be the case that this limitation has resulted in conservative estimates of the true effect of lead on both outcomes. In other words, it is possible that some children whose mothers' answered *no* to the first lead question (i.e., child been tested for lead exposure?) were actually exposed to lead. Additional research will help to determine whether our findings are replicated using alternative measures of lead exposure.

A final point worth mentioning is that although we did not detect a significant effect of lead on language development for females in the sample, this is not to suggest that females are impervious to the deleterious influences of lead exposure. Lead has been linked to a host of negative outcomes, including severe medical complications, in both males and females. And as previous researchers have pointed out, it is unlikely that there is a "safe" level of lead exposure [28]. Our findings suggest that continued efforts aimed at removing environmental sources of lead may not only further limit the risk of medical and neurological complications, but may also help to blunt the development of behavioral problems and language delays in males.

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³ It is worth reiterating (see Figure 2) that the level of statistical significance in the model predicting verbal ability for males fell just above the .05 and just below the .10 thresholds for statistical significance—as might be expected given the further restriction in sample size. Even so, these results are best viewed with cautious interpretation regarding the influence of lead on language ability in males.

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