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Validation and Assessment of Pediatric Lead Screener Questions for Primary Prevention of Lead Exposure

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Abstract

Objective. Pediatric lead screener questions have previously been evaluated for their ability to identify children whose blood lead levels (BLLs) are greater than 10 μg/dL. Based on recent policy changes stressing that there is no safe BLL for children, the current study reevaluates the screener questions for their ability to identify children with BLLs less than 2 μg/dL and the validity of the questions in positively identifying those at greater risk for exposure. *Method*. A total of 202 parents of children enrolled in Head Start programs were administered the pediatric lead screener, questions to validate the screener questions, and children's BLLs were collected in Summer 2013. Pediatric screener questions were validated against children's BLL and the more comprehensive questions on lead risk. *Results*. In predicting BLL greater than 2 μg/dL, the pediatrician screener tool had a sensitivity of 26.3% and specificity of 72.2%. Each of the screener questions had low sensitivities for identifying children with BLLs above 2 μg/dL. The screener questions did not demonstrate adequate validity when compared against a more comprehensive battery of lead exposure risk indicators. The validation questions improved sensitivity to detect children with BLL >2 μg/dL and reduced the number of false positives. *Conclusion*. The pediatrician screener questions in their current format are not a useful primary prevention tool in identifying children at greater risk for lead exposure and in need of secondary prevention through the receipt of a blood lead test. A revision to the protocol for identifying children at risk could result in better primary and secondary prevention efforts.

Keywords
lead exposure, primary prevention, pediatric screeners

Introduction

Great strides have been made to reduce the prevalence of childhood lead exposure, most likely due to the continued reduction in the blood lead level (BLL) at which a child is identified as needing public health initiatives to reduce and monitor their lead exposure. Policy changes reduced this action level to 60 μg/dL in the 1960s; 30 μg/dL in 1975; 25 μg/dL in 1985; and 10 μg/dL in 1991, prior to the current recommendation that children with BLLs above or equal to 5 μg/dL receive services and the acknowledgement that there is no safe BLL for children.[1,2] Along with these reductions in the action level, the national average BLL for children has followed suit, decreasing from 15 μg/dL in the 1970s to 2.7 μg/dL at the beginning of the millennium, and further decreasing to the current average of 1.3 μg/dL (confidence interval = 1.3-1.4).[2,3] An environmental health goal of Healthy People 2020 is to further decrease the national average BLL in children.[4] Even with this latest policy change, researchers have argued to reduce the action level to as low as 2 μg/dL under the rationale that it is a concrete and achievable goal that would minimize the irreversible societal damages of childhood lead exposure.[5]

With this shift in policy comes a call for a shift in thinking and a renewed interest in primary prevention tactics.[6] Currently, the Centers for Disease Control and the American Academy of Pediatrics recommends pediatricians engage in primary prevention through the use of five pediatric screening questions (see Table 1). Parents and guardians should be asked these questions to identify children with greater environmental risk from

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Table 1. Lead Exposure Screener Questions, Validation Questions, and the Prevalence of Risk Reported by Guardians (N = 202)[a].

Pediatrician Screening Questions	Flagged "At Risk" by Pediatric Screener Question	Validation Questions Compared to the Pediatric Screening Question	Validation Questions Sum Score Average, SD, and Range	Flagged "At Risk" by Validation Questions With Low Cutoff	Flagged "At Risk" by Validation Questions With High Cutoff
1. Does your child live in or regularly visit a house built before 1978 which has peeling or chipping paint?	17.1%	1. Do you, or have you in the past year, lived in or spent 10 hours a week or more in a house built before 1978 while remodeling or renovations were being done?	1.61 (SD = 1.29); range = 0-6	78.7%	48.5%
2. Does your child live in or regularly visit a house built before 1978 with recent, ongoing or planned renovations or remodeling?	10.9%	2. In your home, do you have any of the following: pottery or ceramics from other countries, lead sealed plumbing, lead sealed cans, lead paint, mini-blinds, metal-based jewelry, and/or soil or dust that may contain lead in their home			
3. Does your child have a brother, sister, housemate, or playmate who is followed or treated for lead poisoning?	1.0%	No comparison	—	—	
4. Does your child live with an adult whose job or hobby involves exposure to lead?	10.5%	1. Self-reported employment site coded for lead risk 2. Do you or an individual you live with have a hobby that uses lead among the following listed: glazed pottery making, target shooting at a firing range, reloading cartridges and lead shot, stained glass making, molding fishing sinkers, bullets, car, or boat repair, home remodeling, furniture refinishing	0.53 (SD = 0.91); range = 0-5	34.2%	13.9%
5. Does your child live near an industry that is likely to release lead (such as battery plant, lead smelter, or manufacturing plant where lead may be used)?	1.4%	Construction and industrial risk scores based on participant zip codes 1 = low risk, 2 = moderate risk (construction or industrial risk), 3 = high risk (construction and industrial risk)	1.98 (SD = 0.93); range = 1-3	55.0%	40.6%

[a]In a retrospective report, 41.8% of participants remembered a pediatrician asking them the pediatric screener questions. Low cutoff validation questions dichotomized risk by the presence of 1 risk factor while high cutoff validation questions dichotomized risk by the presence of at least 2 risk factors. The validation questions compared to both home pediatric screener questions were the same, so only one value is presented for the sum score and at-risk percentages.

their home or neighborhood, parents' hobbies and employment, or proximity to other children with exposure.[7-10] Those deemed at higher risk due to these screeners receive secondary prevention efforts through blood lead tests. Some families are automatically required to receive secondary prevention tactics, such as Medicaid recipients and families with children enrolled in Head Start programs.[11]

After the 1991 policy change, the pediatric screener questions' sensitivity and specificity for targeting children with BLLs greater than or equal to 10 μg/dL were evaluated in several different studies in a variety of populations. Overall, the questionnaire was not found to be a useful tool to detect children with BLLs greater than or equal to 10 μg/dL.[10,12-14] Shortly after the 1991 policy change, the sensitivity of the screening questions on 330 children in a clinical setting suggested that only the two questions related to the home had sensitivities higher than 10%.[14] In fact, using the two screening questions alone was just as sensitive in identifying children with BLLs above 10 µg/dL as using all five of the screener questions combined. A more recent study investigating a community sample of 69 children from Head Start suggested that the results of the pediatric screener questions are not associated with children's BLL and may not be a useful tool in identifying children with lower levels of exposure.[12] A systematic review of 20 different studies that investigated the effectiveness of the pediatrician screener questions indicated that the questionnaire does not differentiate children at greater risk more than chance and that different methods of detecting children at risk for lead exposure should be established.[10] This meta-analysis was restricted to studies investigating the questions against the previous level of action (ie, 10 µg/dL), as the authors lamented that there were not studies using the current action level available for inclusion in their investigation.

Lead screener questions dichotomize children into risk factors either being present, or not, but parents may not be educated properly on lead exposure risks or sources of exposure to know whether they are answering the questions accurately.[15,16] In this manner, the screener questions may have poor construct validity. For example, both questions related to the home make it crucial that parents know whether or not their house was built prior to 1978. One study investigating the accuracy of parental responses to the pediatrician screener question demonstrated that parents did not correctly report the age of their houses 48% of the time.[17] Living in an older home is a major risk factor for lead exposure, so the low sensitivity of the pediatrician screener may be due in part to parents inaccurately reporting the age of their homes or misunderstanding lead risk factors.[15,17]

Current research questioning the usefulness of the screener questions, in conjunction with the recent reduction in the action level, make it necessary to investigate whether the questions adequately screen for the risk factors for which they are intended and if they are effective at flagging children with lower BLLs than the 1991 level of action. First, this study replicates prior research examining the sensitivity, specificity, and positive and negative predictive values of the lead screening questions for identifying children with detectible BLLs above 2 µg/dL in a Head Start program. Second, the screener questions' construct validity is examined by comparing parents' answers to a more comprehensive battery of questions and geographic risk information.

Table 2. Child and Parent Demographic Characteristics for Total Study Sample[a].

Child	
Gender	47.4% female
Race	
Caucasian	34.2%
African American	33.8%
Hispanic	10.8%
Other	3.9%
Blood lead levels (n = 172)	
>2 µg/dL	11.2%
Guardian	
Biological parent of child	93%
Educational status	
Less than High school	7.3%
High school diploma or GED	50.9%
Some college or vocational classes	30.1%
College degree	11.7%

[a]The 34 children with blood lead levels listed as "<3" by their doctors were placed in the less than 2 µg/dL category because it was assumed this report indicated the level was below detection.

Method

Parents and guardians of children attending a Head Start program in a large southeastern city were given surveys related to lead exposure risk in July 2013. The surveys included the pediatric lead screener questions and a more comprehensive battery of questions relevant to lead exposure risk with which to validate the screener questions. This information was matched to children's BLLs that were on file at Head Start, which were collected from the children's pediatricians or directly by capillary blood lead tests conducted by a nurse through the school and analyzed at a certified, off-site laboratory. Data analysis was conducted between Fall 2014 and Spring 2015. The current study assessed the ability to detect BLLs above 2 µg/dL because this would differentiate children who are approximately above and below the national average.[4] Furthermore, this level has been argued to be an achievable and more concrete goal for minimizing the irreversible damages of lead exposure as adverse effects of exposure have been seen in levels as low as 2.5 µg/dL.[4,5,18]

Due to the qualification requirements for Head Start, all the children were eligible for Medicaid and were from low-income families. Table 2 presents demographic characteristics of the study sample; while 202 families completed all the questionnaires for the study, only 172 children had a BLL available for the analysis. The children were between 3 and 5 years of age. The study was approved by the institutional review board of the school and university and informed consent was obtained from all participants. Parents were compensated for their time with a children's book.

Lead Risk Questions: Home, Hobbies, Employment

To assess the validity of the screener questions in detecting risk, parents were asked a more comprehensive battery of questions on lead exposure risk that matched up to 4 of the 5 screener questions; there were no questions matching to whether or not the child was around another exposed child. Table 1 presents the questions used to compare to each pediatric screener question. For example, to assess the dichotomous question of whether or not an individual in the household has a job or hobby that contains lead, participants were queried on the employment of all adults in the house, and these open-ended answers were coded based on whether or not there was potential for lead contamination on the job-site (eg, car repair, factory work, construction work). Research assistants double coded the employment risk and maintained good interrater reliability (Cohen's $\kappa = .88$). Furthermore, parents were presented a list of hobbies that contain lead and asked if they engaged in any of the listed activities (eg, glazed pottery making, target shooting at firing ranges, reloading cartridges, stained glass making, molding fishing sinkers or bullets, car or boat repair, home remodeling, and furniture refinishing).

To assess the industry screener question, participants' risk for lead exposure due to construction and industrial sites near their home were evaluated using public information on zip codes. To assess potential industry risk factors in a zip code, the number of places listed as major facilities with toxin releases (eg, auto body shops, factories, airports) were identified with a public website (http://www.epa.gov/enviro/facts/topicsearch.html#toxics; accessed April 27, 2014). These included facilities that are a part of the Toxics Release Inventory (TRI), a system used by the Environmental Protection Agency (EPA) to track and monitor pollution and toxin release by facilities. If a zip code had a number of potential industrial risk sites above the median, the participant was identified as having higher industry risk. The percentage of the population working in construction in each zip code was found via census information (http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml; Accessed February 12, 2014); if a participant lived in a zip code that fell above the median for percentage of construction workers, the participant was identified as having higher construction risk. If a participant was identified as having either an industrial or construction risk, they received a score of 1, or a moderate geographic risk, on the validation variable. A score of 2, or a high geographic risk, was given if they had both construction and industry risk based on their zip code. Parents reported living in 23 zip codes across the sample, although 2 zip codes had no information relevant to toxins, and had to be excluded.

Two levels of risk were calculated based on these validation questions matching the screener questions, one more stringent than the other (see Table 1). The *low cutoff* would classify children at risk if there was an affirmative answer to any of the questions related to the home or job and hobbies, and if they lived in a zip code with either construction or industry risk. For example, 8 hobbies were listed on the questionnaire that contained lead exposure risk and parents' reports of their employment were coded; a parent would only have to answer affirmatively to having one of the 8 hobbies or have one adult in the household coded as being in a job at risk for lead to be flagged as at-risk. The *high cutoff* would classify children at risk if there were at least 2 risks related to the home or job and hobbies and their zip code risk included both industrial and construction risk.

Results

One hundred and thirty children (72.6%) were deemed not at risk for lead exposure based on the pediatrician screener questions because the parents answered "no" to all of the questions. Based on the more comprehensive battery of questions used to validate the screener questions, 92.4% were flagged as having potential risk for exposure; 11.1% ($n = 19$) of the sample demonstrated lead exposure based on a BLL above 2 μg/dL. Table 1 presents the percentage of the sample that would be flagged as at risk for exposure based on the pediatric screener question categories (ie, home, job/hobby, industry).

To examine the validity of the screener questions, all analyses were conducted using SPSS version 19. Table 3 presents the high and low cutoffs of the validation variables as compared to the risk classification children received based on the pediatric screener by presenting a contingency table of how many participants would be classified as at risk by either the screener, validation question, or both. A κ coefficient provides the agreement between the screener and validation questions in identifying a child at risk for lead exposure. Significant κ values indicated slight agreement between the dichotomous screener questions and more comprehensive validation questions for identifying home risk (i.e., κ between .01 and .2) and fair agreement in identifying risk from a job or hobby (i.e., κ between .21 and .40).[19] There was no agreement between the 2 measures of risk from industry.

Table 3. Prevalence of Affirmative Answers to Screener Questions Compared Low and High Cutoffs for Validation Questions (N = 202)[a].

	Affirmative to Both	Affirmative Only to Pediatric Screener Question	Yes Only to Validation Question	Kappa
Low cutoff				
Chipping or peeling paint	32	4	127	.05 (p = .10)
Remodeling	21	1	140	.049 (p < .05)
Job or hobby	20	2	49	.33 (p < .001)
Industry	2	1	109	.01 (p = .69)
High cutoff				
Chipping or peeling paint	27	9	71	.19 (p < .01)
Remodeling	16	6	82	.12 (p < .05)
Job or hobby	12	10	16	.41 (p < .001)
Industry	2	1	80	.02 (p = .37)

[a]Low cutoff validation questions dichotomized risk by the presence of 1 risk factor while high cutoff validation questions dichotomized risk by the presence of at least 2 risk factors.

When comparing the average on the validation index of those who answered affirmatively on the pediatric screener questions to those answering negatively, there was a significantly higher average for those who answered affirmatively to having chipping or peeling paint, $t(198) = 3.29$, $p < .01$, remodeling or renovations in their home, $t(199) = 2.55$, $p < .05$, and a job or hobby that contained lead, $t(202) = 8.28$, $p < .001$, but not for zip code risk, likely due to the small sample size (n = 3) who answered affirmatively to this question on the screener.

Table 4 reports on the sensitivity, specificity, and positive and negative predictive values of identifying children with BLLs > 2 µg/dL for the following: the existing pediatric screener questions; the more comprehensive risk questions with a low cutoff value (i.e., only answered affirmatively to one validation question); and the more comprehensive risk questions with a high cutoff value (i.e., at least 2 affirmative risk items from validation questions). For the pediatric screener questions, sensitivity ranged from 0% to 16.7%; specificity ranged from 83.7% to 99.1%. Sensitivity improved with the low cutoff (range = 58% to 100%) and high cutoff (21.1% to 66.7%), while specificity lowered (low cutoff: range = 8.8% to 68.1%; high cutoff: range = 49.0% to 86.6%).

Discussion

Identifying children at greater risk for lead exposure is critical, as children with levels below 10 µg/dL likely do not present with behavioral or neurological symptoms, but are still at risk for detrimental short and long-term consequences of exposure.[9] Application of an effective screening method for targeting children at risk for lead exposure is an important primary prevention strategy to reduce childhood lead exposure, which could yield larger economic benefits than the costs of universal BLL testing and removing lead from the environment.[20] To be useful, however, a lead screening process should provide good sensitivity, so that children at risk are flagged, but adequate specificity, so that it is cost and time effective in identifying children needing secondary prevention efforts.

Combining our study with results from previous research suggests the current pediatric lead screener questions demonstrate low sensitivity for identifying children with lead levels of concern whether using the old action level or our more conservative cutoff of 2 µg/dL.[10,12,13] The pediatric screener has a low sensitivity and high specificity indicating that the screener identifies children that are not at risk, but does not catch all of the children at risk. The low sensitivity of the test is likely because the questions have poor construct validity and are not good indicators of children's true risk for exposure, as was demonstrated with the coefficient of agreement between the existing and validation questions.[14]

These questions need to be reexamined both in content and practice to optimize their potential in primary prevention efforts. For example, the more comprehensive risk index used in the present study improved the ability to identify children whose BLLs were above 2 µg/dL for home, job and hobby, and industry risk, but increased the number of false positives that would be flagged. If this more comprehensive approach to screening was implemented, more children who were truly at risk would be flagged, but many children who were not would also be included in secondary prevention efforts. Future studies should aim to refine the questionnaire to

Table 4. Sensitivity and Specificity of Screener Questions and Validation Questions for Identifying BLLs Above 2 μg/dL (N = 172)[a].

Question	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
Existing pediatric screener differentiating children with and without a BLL > 2 μg/dL				
1. Chipping paint	16.7%	83.7%	10.7%	89.5%
2. Remodel risk	0%	89.0%	0%	88.4%
3. Contact with exposed individuals	0%	98.7%	0%	89.4%
4. Job or hobby exposure	15.8%	99.1%	17.7%	90.0%
5. Industry	0%	98.1%	0%	80.4%
6. Affirmative to at least one screener question	26.3%	72.2%	10.2%	89.1%
7. Affirmative to at least one home question	16.7%	80.0%	8.8%	89.2%
At least 1 affirmative answer on validation questions differentiating children with and without a BLL > 2 μg/dL (low cutoff)				
1. Home risk questions	84.2%	22.5%	11.4%	92.3%
2.Job or hobby exposure	58.0%	68.1%	17.7%	93.2%
3. Industry	88.9%	22.3%	11.6%	94.6%
4. Affirmative to at least one validation question	100%	8.8%	11.5%	100%
More stringent cutoff of validation questions differentiating children with and without a BLL > 2 μg/dL (high cutoff)				
1. Home risk questions	33.3%	49.0%	7.1%	86.4%
2. Job or hobby exposure	21.1%	86.2%	15.4%	90.1%
3. Industry Risk	44.0%	60.6%	11.6%	90.4%
4. Affirmative to at least one validation question	66.7%	30.8%	10.0%	88.9%

Abbreviation: BLL, blood lead level.
[a]No questions were administered to participants that made it possible to assess the sensitivity and specificity of the screener question related to a child coming in contact with other exposed individuals. Home questions were combined for the validation questions.

improve on their specificity, but it is optimistic that sensitivity can be improved with expansions to the existing questions.

Besides considering different variations of the questions to better predict children in need of secondary prevention measures, future research should also consider a different rationale for why the screening questions are used. With the current policy focus on primary prevention, screener questions could also be viewed as an indicator of whether a brief discussion of lead risk factors should be conducted with parents.[7,9] Brief pediatric interventions have been effective in educating parents on their children's health behavior risk[20,21] and have been recommended to be tailored for and targeted at more at-risk communities and individuals.[21,22]

The implementation of the screening question could utilize current technology to facilitate more consistent and comprehensive use. For example, tablets or a paper-and-pencil measure could be used in the pediatrician's waiting room to assess whether or not a lead test or brief discussion on lead risk is warranted during the exam. Furthermore, amended screening questions could be supplemented with geographical risk indicators.[22] In our research, an assessment of risk by the identified zip code gained the highest sensitivity, although the specificity would still result in 77.7% of false positives for the low cutoff and 39.4% for the high cutoff. The lead screening questionnaires could be supplemented with more advanced techniques such as geographic information system analysis to pinpoint children living in high-risk areas.[9,10] Studies that have used geographic assessments to determine lead exposure risk have been successful in identifying children with elevated BLLs.[23-25] In fact, when compared to the pediatrician screener, a geographic risk score had a higher sensitivity and positive predictive value, and progressive policy in states like Ohio have moved to using zip codes in conjunction with the lead screener questions (John Belt, personal communications, February 2014).[24]

Limitations

The current study used a community sample in a region of the country with generally lower lead exposure risk. In this manner, it was an ideal sample for assessing if the screener questions were effective for detecting lower levels of risk; however, study replication in a region with higher exposure risk is warranted. Another point of consideration is that the lead tests of the sample were provided by doctors' offices, resulting in differences in blood analysis and reporting; for example, it is unknown if children received venous or capillary blood draws and the exact BLL for children was not always listed (eg, <3 μg/dL) by their doctors. These BLLs had to be coded as less than 2 even though it is feasible the children may have had BLLs greater than 2 given the confidence intervals of lead testing.

Conclusion

Pediatric screening tools for identifying children at risk for lead exposure is one concrete way the costs and consequences of lead exposure could be reduced. If the screening tool is not a valid assessment of risk, and does not adequately differentiate those in need of secondary prevention tactics, then this primary prevention approach falls short of its usefulness.[14,26] The goals of Healthy People 2020 include a focus on primary prevention of lead exposure and a reduction of elevated BLLs in children.[7] To accomplish this based on our more progressive stance on lead exposure risk, research is needed on how to improve, and perhaps rethink, the screening approach currently in place.[9,13]

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Author Contributions

JN contributed to the study design, data collection, analyses, and interpretation, and drafting of the manuscript. MC assisted JN in all aspects of the study, manuscript development, and revision. Both authors approved the final version of the manuscript.

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