Lead Poisoning among Young Children in Russia: Concurrent Evaluation of Childhood Lead Exposure in Ekaterinburg, Krasnouralsk, and Volgograd

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The Gore-Chernomyrdin Commission encouraged a binational collaboration to evaluate pediatric lead poisoning in Russia. The study evaluated children in three Russian cities: Krasnouralsk, a small city with minimal traffic centered around a copper smelter; and Ekaterinburg and Volgograd, both of which are large cities with multiple factories and heavy vehicular traffic. This project was the first international use of portable blood lead analysis instruments. In each city, at least 90% of children attending selected neighborhood kindergartens participated. We selected kindergartens on the basis of their proximity to industrial areas and major traffic corridors. We obtained capillary blood samples and analyzed for lead content and hemoglobin (Hgb) levels in the field, and collected environmental samples (i.e., indoor dust, tap water, play area soil, and interior and exterior paint) and analyzed for each participating school and in the homes of about 10% of the children who had elevated blood lead levels (BLLs; ≥ 10 µg/dL). We calculated all age-, sex-, and city-specific geometric means using generalized estimating equations to account for covariance within kindergartens, and used multivariate logistic regression models to identify variables predictive of elevated BLLs. Overall, 23% of study children had elevated BLLs and 2% were anemic, defined as Hgb < 11 g/dL. Krasnouralsk had the highest geometric mean BLL (10.7 µg/dL), the highest percentage of children (60%) with elevated BLLs, and the highest percentage of anemic children (4%). All soil samples in Krasnouralsk had detectable lead levels. Volgograd was the only city that had paint samples with elevated lead levels. We found apparent city-specific differences in the percentages of children with elevated BLLs. Lead-contaminated soil and dust, which can result from lead-based automotive fuel and from lead-related industrial emissions, appear to be the most important routes of lead exposure of those evaluated in this study. Elevated lead levels found in paint samples from Volgograd may indicate old undercoats of lead-based paint that could represent a regionally rather than nationally important source of exposure. *Key words:* children's health, environmental exposure, lead poisoning.
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In 1995, the Sanitary Epidemiological Service, Russian Ministry of Health, U.S. Environmental Protection Agency (EPA), and the U.S. Centers for Disease Control and Prevention (CDC) cosponsored a workshop in Moscow titled "The Health Effects of Lead and Other Heavy Metals in Russian Children." Before that meeting, Russian health officials primarily analyzed hair to test for lead poisoning in children. The workshop led to a binational cooperative field investigation in Saratov, Russia, during which blood and hair samples were collected from almost 600 children 6 years old or younger (*1*). A portion of the samples was split and then analyzed simultaneously in Moscow and in the United States at the CDC's National Center for Environmental Health (NCEH) laboratory in Atlanta, Georgia. Twenty-four percent of children had blood lead levels (BLLs) ≥ 10 µg/dL, the CDC level of concern (*2*). The geometric mean BLL was 7.7 µg/dL. Although leaded gasoline was identified as an important source of exposure, two point sources—a battery factory and a leaded glass facility—also were implicated as sources of exposure to lead. In addition, analysis of hair poorly predicted BLLs > 10 µg/dL. The results of this first large-scale study of BLLs in Russian children stimulated interest in assessing the extent of lead poisoning among Russian children in other cities and in identifying sources of lead exposure (*3*).

In 1996, under the auspices of the Gore-Chernomyrdin Commission's Environmental Health Priority Area, NCEH and the Sanitary Epidemiological Service began planning a three-city survey of pediatric lead poisoning that would include analysis of biologic (i.e., blood) and environmental (i.e., dust, soil, water, and paint) samples. The expanded study was planned to use a portable blood lead analysis instrument recently approved by the U.S. Food and Drug Administration (LeadCare; ESA, Inc., Chelmsford, MA, USA) so that Russian public health officials would have BLL results in a time frame compatible with meaningful intervention if we identified lead poisoning. We developed a protocol detailing the evaluation that included consent forms and data release plans. Because the determination of childhood lead poisoning prevalence in these communities is a public health practice intended to enable effective local intervention strategies, the project was not considered human subjects research and was not reviewed by the CDC Institutional Review Board.

Methods

Site and sample selection. The Russian investigators selected Ekaterinburg, Krasnouralsk, and Volgograd because these cities provided a variety of potential sources for lead exposure. Ekaterinburg and Volgograd are large industrial cities (population ~ 1,000,000) with heavy traffic. Ekaterinburg is 1,400 km east of Moscow in the Ural Mountains, and Volgograd is 900 km southeast of Moscow along the Volga River. These cities have both stationary (e.g., industrial emissions) and mobile (e.g., automobile emissions) sources of lead exposure. Krasnouralsk, a small city (population ~ 30,000) in the Ural Mountains approximately 200 km north of Ekaterinburg, has a large copper smelting plant and no significant automotive traffic. Although Russia is moving toward a national ban on the use of leaded gasoline, at the time of this survey (1997) both leaded and unleaded gasolines were available for purchase in each of the cities.

Local health officials in each city selected neighborhood kindergartens and preschools to participate in this study on the basis of their proximity to industrial sectors and major traffic corridors. Local school officials reported that children almost always attended schools closest to their homes or schools affiliated with their parents' employers. Most of the kindergarten/preschools enrolled children as young as 2 years old, but most of the children were 4–6 years old. Before initiating the field study, we gave parents and teachers materials explaining the study objectives and logistics for data collection. At least 90% of the children in each classroom turned in

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signed consent forms to participate and were therefore eligible for enrollment in the study. Each child's parent completed a questionnaire that requested information about family demographic, occupation, and type of housing. Although we restricted analysis to children 2–6 years old, as a community service we measured BLL of every child who presented a signed consent form.

Blood lead and hemoglobin analyses. We used the same technique for capillary blood sampling and collection as in the Saratov study (*1*). However, in our three-city study, we analyzed capillary blood samples in the field for lead concentration using newly developed portable technology. CDC staff trained teams of Russian nurses to collect and analyze capillary blood and environmental samples. Under the supervision of the CDC team, Russian health care workers obtained the capillary blood samples from the children and analyzed the specimens on site for lead using battery-powered portable instruments. This portable technology permitted the study team to provide test results and educational information immediately to parents and teachers in each classroom.

The portable blood lead instrument quantifies lead levels in fresh whole blood using reagents and an electrochemical sensor, using anodic stripping voltammetry. In the field, we calibrated all of the instruments daily and analyzed quality control (QC) materials before and after each analytical run. When a BLL was ≥ 35 µg/dL, we validated the calibration of the instrument using a stock lead standard from the Blood Lead Laboratory Reference System (*4*). We recorded the results of QC procedures daily into an analysis log for each instrument.

We split and froze all field samples and upon completion of the field study sent them to the CDC for evaluation of the accuracy of the portable testing system. However, only 427 samples were cleared through Russian customs and available for analysis at the CDC/NCEH laboratory. There, we thawed the samples and analyzed them by graphite furnace atomic absorption spectrometry using the method described by Miller et al. (*5*).

To test children for anemia [hemoglobin (Hgb) < 11.0 g/dL] (*6*), we also analyzed capillary blood samples in the field for Hgb using a battery-powered portable HemoCue B-Hemoglobin Analyzer (HemoCue, Inc., Mission Viejo, CA, USA) instrument. Calibration of the HemoCue instruments was confirmed if the instruments measured a value within 0.3 g/dL of a manufacturer-supplied cuvette filter. Each day, we verified the analytical accuracy of the instruments using a manufacturer-supplied bovine-based QC material (Hemotrol) containing three levels of Hgb (8.0 ± 0.4 g/dL, 12.2 ± 0.6 g/dL, 16.0 ± 8.0 g/dL).

Environmental samples. The methods we used to collect and analyze environmental samples, ultrasonic extraction procedures, and anodic stripping voltammetry instrumentation have been detailed elsewhere (*1*). CDC researchers trained Russian scientists to collect and analyze environmental samples for lead content. We collected two water samples [limit of detection (LOD), 2 µg/L], at least two dust-wipe samples (LOD, 25 µg/sample), at least two paint samples (LOD, 0.02 mg/sample), and at least one playground soil sample (LOD, 25 µg/sample) from all participating kindergartens and from a subsample of homes of children whose blood we tested for lead during this study. We intended to collect environmental samples from the homes of all children in each city who had the highest BLLs, but because of logistical constraints we collected samples only from homes of approximately 10% of children who had BLLs ≥ 10 µg/dL.

Statistical analysis. We included only children 2–6 years old in analyses, which we performed using SAS, version 8.01. We calculated the geometric mean for BLL and Hgb measures, because these variables were not normally distributed. We calculated all age-, sex-, and city-specific geometric means using generalized estimating equations to account for covariance within kindergartens. Dichotomous variables for BLLs were < 10 µg/dL and ≥ 10 µg/dL (excess lead exposure) and for Hgb concentrations were < 11.0 g/dL (anemic) and ≥ 11.0 g/dL. We used multivariate logistic regression to determine whether associations existed between elevated lead values (i.e., BLL ≥ 10 µg/dL) and covariates. The probability level used to determine statistical significance in all analyses was 0.05.

Results

Demographic distribution of BLL. We collected capillary blood samples from 1,199 children in three Russian cities: 659 children from seven kindergartens in Ekaterinburg, 234 children from six kindergartens in Krasnouralsk, and 306 children from eight kindergartens in Volgograd. We included in our analysis data from children 2–6 years old who usually attended the selected kindergartens. We included a total of 1,101 children in the analysis (601 from Ekaterinburg, 219 from Krasnouralsk, and 281 from Volgograd; Table 1). The mean age was 4.9 years (2.0–6.98 years), and 46% were girls. The overall geometric mean BLL of children in the sample was 7.2 µg/dL (2.0–41.7 µg/dL), and the geometric mean Hgb level was 12.8 g/dL (8.9–16.1 g/dL). Two percent of eligible children were anemic (Hgb < 11.0 g/dL), 23% had excess lead exposure (BLL ≥ 10 µg/dL), and 1% met U.S. criteria for lead poisoning (BLL ≥ 20 µg/dL).

The geometric mean Hgb level for children who also had excess lead exposure was 12.8 g/dL (range 8.9–15.2 g/dL) and was not significantly different from the geometric mean Hgb level of children who had BLLs below 10 µg/dL (12.9 g/dL, 10.1–16.1 g/dL). The geometric mean BLL for boys was higher than that of girls, and boys were more likely than girls to have excess lead exposure in all three cities (Tables 2 and 3). Although the geometric mean BLLs differed among age groups, differences were city specific; none of the cities showed a consistent increase or decrease in BLLs by year of age (Table 2).

Children who lived in Krasnouralsk had the highest overall geometric mean BLL [10.7 mg/dL, 95% confidence interval (95% CI) = 10.2–11.2 mg/dL], a statistically significant finding, and the highest geometric mean BLL for every age group. Krasnouralsk had the highest percentage of children with excess lead levels (60%), the highest percentage of anemic children (4%), and the highest percentage of children who met the U.S. criteria for lead poisoning (2%; Table 1). We found a strong and statistically significant association between living in Krasnouralsk and having excess lead exposure relative to children who lived in Ekaterinburg [odds ratio (OR) = 12.5, 95% CI = 8.6–18.1]. Children living in Volgograd were only twice as likely to have excess lead exposure as those living in Ekaterinburg (OR = 2.0, 95% CI = 1.3–3.0).

Kindergarten-specific geometric mean BLLs differed significantly in Ekaterinburg and Volgograd. However, the location of the schools was not discernibly associated with a specific source of lead exposure.

Portable analysis versus atomic absorption spectroscopy. Obtaining a blood sample by venipuncture has been the traditionally preferred method for blood lead definition. However, samples obtained through fingerstick sampling are much more applicable to a field sampling protocol and, when performed properly by trained personnel, are comparable to venipuncture testing (*7–9*). We carefully trained all U.S. and Russian blood collection personnel in the procedure and validated the portable instrument analysis with laboratory based analysis, as has been reported in other studies (*10,11*). The concentration of lead in the 427 split capillary blood samples as measured by the LeadCare instrument in the field correlated well (R^2 = 0.74, slope 0.99, intercept 1.69) with measurements from the CDC/NCEH laboratory. We did find variation by city (R^2 varied from 0.46 to 0.83, intercept from 1.17 to 4.77), by analyst, and by instrument. Most of the variation, however, was below BLL concentration of 10 µg/dL.

Environmental sample results. **Kindergartens.** In Ekaterinburg, we tested dust, soil, paint, and water samples for lead from seven kindergartens. Only one school had elevated environmental measurements, and that only in dust samples (range, 41–46 μg/ft^2). Detected dust lead levels were above the current U.S. Housing and Urban Development (HUD) interim clearance standard for lead in dust of 40 μg/ft^2, which is down from the standard set in 1997 of 100 μg/ft^2 (*12*). We detected some lead in a few of the play yard soil samples, although not at elevated levels (range, 56–88 ppm). The standard for lead in soil established by the U.S. EPA is 400 ppm (*13*). We did not detect levels of lead above the current U.S. standards in paint collected from schools in Ekaterinburg, nor did we detect lead in water samples.

In Krasnouralsk, only one of the six kindergartens sampled had an elevated dust lead level, but it did not exceed the current HUD standard for lead in dust. Every soil sample collected from kindergartens contained lead concentrations of 93–211 ppm; none of the soil samples were above the U.S. EPA standard. Paint and water samples did not have elevated lead levels. In Volgograd, we did not detect lead in dust, soil, or water samples collected from kindergartens. However, five of the eight kindergartens had paint lead levels that exceeded the standard for lead in paint of 5,000 ppm set by HUD (*7*).

Homes. Logistic constraints limited the sampling of children's homes to 26 homes in Ekaterinburg, 22 in Krasnouralsk, and 18 in Volgograd. Seven homes (26%) in Ekaterinburg had dust lead levels greater than the current HUD dust lead standard, and four homes (15%) had dust lead levels greater than the 1997 HUD standard. One home (4%) had detectable, although not elevated, levels of lead in soil (83 ppm). We detected no lead in water or paint samples collected from Ekaterinburg.

Three homes (14%) in Krasnouralsk exceeded the current HUD standard for dust; no homes exceeded the 1997 standard. Lead concentrations in soil samples collected from play areas outside homes in Krasnouralsk ranged from 93 ppm to 858 ppm, and lead levels in two homes exceeded the EPA soil lead standard. We detected no lead in paint or water samples collected from homes in Krasnouralsk.

Levels of lead were elevated in dust samples from 12 (67%) of the homes tested in Volgograd. In six homes (33%), dust lead levels exceeded the 1997 HUD standard. A child living in one of these homes had a BLL of 35.7 μg/dL. Lead levels were markedly elevated in all the dust samples taken from this home, the highest 39,000 mg/ft^2. Four homes (22%) exceeded the HUD paint lead standard of 5,000 ppm. We found no lead in samples of water or in soil samples collected from homes in Volgograd.

Models to predict excess lead exposure. We created a multivariate logistic regression model for each city independently because patterns of association among age categories differed in each city (Table 3). We defined excess lead exposure for each model as BLL of ≥ 10 μg/dL. Hgb levels were not significant, so we did not include them in the models. All three models included age categories by year, sex, and kindergartens. In Ekaterinburg, an inverse relationship existed between BLL and age, with BLL decreasing as age increases, except among 4-year-old children. In Volgograd, 3- and 4-year-old children appeared more likely to have elevated BLLs. In Krasnouralsk, this relation occurred among 3- and 5-year-old children. Girls in all three cities were less likely to have excess lead exposure than were boys, although this relation was statistically significant in Volgograd only. Elevated BLLs were more likely to vary among kindergarten children in Ekaterinburg and Volgograd than among children in Krasnouralsk.

Table 1. Frequency and distribution of children tested for BLL and Hgb levels during an evaluation in three Russian cities in October 1997.

	City			
	Ekaterinburg	Krasnouralsk	Volgograd	Overall
Age (years), mean (range)	4.7 (2.0–7.0)	5.1 (2.0–7.0)	5.0 (2.1–7.0)	4.9 (2.0–7.0)
No. girls (%)	601 (46)	219 (43)	281 (47)	1,101 (46)
BLL (μg/dL), GM (95 % CI)	6.4 (5.9–6.9)	10.7 (10.2–11.2)	6.8 (6.1–7.5)	7.2 (7.0–7.4)
Excess lead > 10 μg/dL (%)	66 (11)	131 (60)	53 (19)	252 (23)
Excess lead > 20 μg/dL (%)	6 (1)	5 (2)	3 (1)	14 (4)
Hgb (g/dL), GM (95 % CI)	12.8 (12.7–13.0)	12.7 (12.4–13.1)	12.8 (12.7–13.0)	12.8 (12.8–12.9)
Anemia (Hgb < 11 g/dL), no. (%)	8 (1)	8 (4)	3(1)	19 (2)

GM, geometric mean.

Table 2. Geometric mean BLL (95% CI) by year of age and by sex for each of the three cities.

Age (years)	Ekaterinburg	Krasnouralsk	Volgograd
2	7.0 (6.3–7.7)	10.5 (9.4–11.6)	7.2 (5.5–9.3)
3	6.6 (6.1–7.1)	10.9 (9.9–12.1)	7.0 (6.3–7.7)
4	6.7 (6.0–7.5)	10.5 (9.2–12.0)	7.4 (6.5–8.4)
5	5.9 (5.3–6.5)	11.7 (11.1–12.3)	7.0 (6.2–7.8)
6	6.1 (5.6–6.8)	10.0 (9.4–10.6)	6.1 (5.3–7.0)
Boys	6.6 (6.0–7.2)	11.1 (10.2–12.1)	7.5 (6.7–8.3)
Girls	6.2 (5.8–6.6)	10.2 (10.0–10.4)	6.1 (5.4–6.8)

Discussion

This project expands on the first BLL assessment of Russian children in Saratov by evaluating children in three other Russian cities. In this project, we evaluated biologic and environmental samples from three cities concurrently using the same methodology and laboratory techniques in each city. However, results varied substantially between the cities. For example, the geometric mean BLL in Krasnouralsk was 67% higher than the geometric mean BLL in Ekaterinburg. Perhaps more striking is the finding that a child in Krasnouralsk was more than five times as likely as a child in Ekaterinburg to have excess lead exposure. Although the geometric mean BLL between Volgograd and Ekaterinburg did not differ greatly, children in Volgograd were at almost twice the risk for excess lead exposure as children from Ekaterinburg. In Ekaterinburg and Volgograd, we were unable to pinpoint specific sources of lead exposure, despite our efforts to compare the geographic location of schools that had high geometric mean BLL with the geographic location of the potential sources of lead exposure.

Geometric mean BLLs in Russian children from this study and the Saratov study were higher than the geometric mean BLL in U.S. children 1–5 years old (1988–1991; 3.6 μg/dL) (*1,14*). However, these Russian children had lower geometric mean BLLs than did the U.S. children surveyed during the previous U.S. national survey (1976–1980; 15.0 mg/dL) (*14*). In both U.S. surveys, risk of lead poisoning was higher among younger children, with the greatest risk among children younger than 2 years. However, although BLL varied significantly by age in each of the three Russian cities that we evaluated, we detected no progressive age trend or consistent pattern of association between age and BLL among the cities. As in the Saratov study, age was not predictive of excessive lead exposure, implying that Russian children may be exposed to lead by different pathways than are U.S. children. However, most of our sampling was among 4- and 5-year-old children. The 2-year-old children in our survey were attending the preschool/kindergarten by choice rather than by norm or mandate and may be less exposed than 2-year-old children living at home, as suggested by more frequent lead detection from our home-collected samples than from our kindergarten-collected samples.

In all three of the Russian cities in our study, boys were at greater risk of lead poisoning than were girls. The geometric mean BLL for girls was consistently lower than the mean among boys living in the same city, and in Volgograd, girls were significantly at half the risk of boys for having a BLL ≥ 10 µg/dL. This same gender difference is consistently found in BLL screening among children living in the United States (*14*).

Analyses of environmental samples collected from schools and homes provided additional information about potential sources of lead exposure. However, because of logistical constraints during the study period, the overall number of environmental samples was lower than anticipated, and the homes identified as eligible for sampling were those where children with the highest BLLs lived. Nonetheless, the results of our study do provide some valuable information. For example, although lead-based paint has not been available recently in the United States or in Russia, paint chips and paint-contaminated house dust are currently the primary source of lead exposure among children in the United States. In contrast, we found that most of the paint samples collected during our study were negative for lead. We did detect lead in paint samples collected from homes and kindergartens in Volgograd; we did not detect lead in dust or soil samples collected from the kindergartens where we identified lead-based paint. This may indicate the presence of undercoats of paint applied in previous decades and could represent a regionally important source of exposure. However, overall we found little evidence that lead-based paint was an important source of lead poisoning among Russian children participating in our three-city study. Similarly, the lack of detectable levels of lead in any water sample suggests that leaded pipes in the water distribution system are not a source of exposure in this population.

The results of our study suggest that dust and soil contamination are important pathways for exposure to lead in this population. Many dust samples collected from homes in each city had elevated lead levels. In Krasnouralsk, we detected lead contamination in every soil sample collected from schools and homes, although most did not exceed U.S. standards. Although the number of environmental samples was small, the fairly low soil and dust levels we found would not have been predictive of the percentage of the population with BLLs ≥ 10 µg/dL (*15*). We were not able to identify the source of lead in dust and soil samples, but we suspect the deposition of lead by airborne emissions from stationary point sources such as the copper smelter in Krasnouralsk as well as the varying presence of emissions from cars still using leaded gasoline. A well-designed air-monitoring program might provide insight into the source of lead in these media.

Many factors limit the generalizability of our results. The populations sampled represent only three cities, and results varied greatly among them. We did not select schools randomly but rather on the basis of their proximity to mobile and point sources of lead. Our study did not include rural populations, so the results do not represent BLLs in the general population of Russian children. In the absence of a random national survey, however, our three-city study provides the best information available about lead exposure in Russian children.

This investigation marks the first international field use of a portable blood lead testing instrument to assess lead exposure in a population. The system provided a rapid and inexpensive means to evaluate BLLs in a large number of persons. Analysis of a subset of samples by the NCEH laboratory verified the accuracy of this technology. We anticipate that portable instruments will be useful in future population studies of lead exposure and also for rapid evaluation of small groups with acute exposure to lead, especially in international settings where access to reference laboratories may be limited and immediate results are preferable.

Our results indicate that excessive BLLs (i.e., lead poisoning) are not prevalent among Russian children, although exposure to lead does appear to be a problem, especially for children living in large industrial cities. This may become more important as the Russian economy improves and industrialization increases. Russian officials indicate that industrial activity in Russia is far below capacity. When such activity increases, Russian children are likely to be exposed to greater environmental lead contamination. The results of our study highlight the need for blood lead surveillance among children in Russia and suggest that future public health research efforts focus on reducing airborne lead emissions from industrial point sources and also from automobile emissions that may persist from any continuing use of leaded gasoline.

Table 3. City-specific multivariate logistic model of OR and 95% CI to predict BLL ≥ 10 µg/dL.

Variable	Ekaterinburg OR (95% CI)	Krasnouralsk OR (95% CI)	Volgograd OR (95% CI)
2-year-olds	4.3 (1.5–12.4)*	0.8 (0.1–4.6)	0.6 (0.1–5.9)
3-year-olds	2.1 (0.7–5.9)	2.3 (0.9–5.6)	1.9 (0.7–5.1)
4-year-olds	3.4 (1.4–8.5)*	1.1 (0.5–2.4)	2.9 (1.1–7.5)
5-year-olds	1.3 (0.5–3.5)	2.3 (1.1–5.0)*	2.4 (0.9–6.2)
6-year-olds (reference group)	1.0	1.0	1.0
Sex (female)	0.6 (0.4–1.1)	0.7 (0.4–1.2)	0.5 (0.2–0.9)*
Kindergarten 1	0.4 (0.1–1.1)	0.9 (0.3–2.8)	6.1 (0.7–58.1)
Kindergarten 2	0.6 (0.2–1.6)	1.0 (0.4–2.6)	1.2 (0.2–8.0)
Kindergarten 3	0.5 (0.1–1.8)	2.1 (0.8–5.4)	0.3 (0.0–3.7)
Kindergarten 4	1.5 (0.5–4.3)	1.5 (0.5–4.0)	2.4 (0.4–14.3)
Kindergarten 5	0.2 (0.1–1.2)*	1.8 (0.6–4.8)	2.6 (0.5–13.8)
Kindergarten 6	0.3 (0.1–1.2)	—	0.9 (0.0–5.3)
Kindergarten 7	—	—	0.9 (0.2–4.6)

*Statistically significant at $p < 0.05$.

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