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Cross-sectional study to assess the association of color vision with mercury hair concentration in children from Brazilian Amazonian riverine communities



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ABSTRACT

Background: Mercury exposure in the Brazilian Amazon region has been an important concern since the 1980s, when gold mining activities contaminated many Amazonian river basins and the fish therein. Mercury exposure in humans can lead to changes in neural function. The visual system has been used as a functional indicator of methylmercury (organic) and mercury vapour (inorganic) toxicity. Children are particularly vulnerable to this metal exposure.

Objective: To compare the color vision of children from riverine communities of mercury-exposed (Tapajós basin) and non-exposed Amazonian rivers (Tocantins basin).

Methods: The study sample was 176 children, aged 7–14 years old. Children from two locations in the mercury-exposed Tapajós river basin, Barreiras (n = 71) and São Luiz do Tapajós (n = 41), were compared to children from Limoeiro do Ajuru (n = 64), a non-exposed area in the Tocantins river basin. No caregiver reported that any children had contact with mercury vapour during their lifetime, and probably most of the mercury in their bodies was obtained by fish consumption. Because of this, we decided to evaluate the mercury exposure by total mercury levels in hair samples, a good marker for organic mercury, and not in the urine, a marker for inorganic mercury. Color vision was assessed by the Lanthony Desaturated D-15 test. We used the Vingrys and King-Smith method (1988) to quantify the hue ordering test. The primary visual outcomes from this analysis were C-index (magnitude of the hue ordering error) and angle of the hue ordering.

Results: The Tapajós children had a higher mean hair mercury level (mean: 4.5 µg/g; range: 0.26–22.38 µg/g) than that of Tocantins children (mean: 0.49 µg/g; range: 0.03–1.91 µg/g) (p < 0.05). Mean difference was approximately 4.01 µg/g with a 95% confidence interval of 2.79–5.23. The results of the Lanthony D-15d test showed no significant difference between the C-index mean values of the Tapajós and Tocantins groups (p > 0.05). There was a weak linear correlation in the average C-index obtained from both eyes and the total mercury concentration. Multiple logistic regression analysis indicated that the location of the community and the age had a greater influence on the visual outcomes than the sex of the children and within-locale variation in mercury concentration.

Conclusion: Our results suggest a difference in one aspect of vision, that is, color vision, between children living in two different river basins in the Brazilian Amazon. The association may be related to Hg exposure but also appeared related to the location of the community and age.

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1. Introduction

Human exposure to mercury occurs by occupational contact and food consumption (Bueno et al., 2011; Cavalleri et al., 1995; Feitosa-Santana et al., 2010; Malm et al., 1995; Souza and Barbosa, 2000; Straaten, 2000; Zavariz and Glina, 1993). The occupational exposure is due to inhalation of mercury vapour, and the environmental exposure occurs by the consumption of food with organic mercury. There is evidence that mercury affects most stages of the visual processing (El-Sherbeeney et al., 2006). Morphological and functional studies in animals and humans showed alterations in the cornea (Grant, 1973; Krachmer and Palay, 1995), iris (Sood et al., 1972), lens (Kipling, 1965; Lemire et al., 2010), retina structure and function (Ventura et al., 2005; da Costa et al., 2008; Ekinici et al., 2014; Brasil et al., 2017), atrophy of the visual cortex, and decrease of its function (Galin and Obstbaum, 1974; Costa et al., 2008; da Costa et al., 2008).

Many reports have associated visual impairments (color vision, contrast sensitivity, visual field, evoked responses) to the inorganic mercury occupational exposure of workers (Cavalleri et al., 1995; Feitosa-Santana et al., 2007, 2008, 2010; Barboni et al., 2008, 2009; Costa et al., 2008; Ventura et al., 2005). Few of these reports tested the strength of this association (Cavalleri et al., 1995; Feitosa-Santana et al., 2007, 2008), which had either intermediate significant correlation (Cavalleri et al., 1995) or no correlation (Feitosa-Santana et al., 2007, 2008). Similarly, other reports have found visual losses in subjects exposed to an organic mercury specie, methylmercury (Lebel et al., 1996; Rodrigues et al., 2007; Kim et al., 2012). They have found weak to intermediate correlation between visual outcomes (contrast sensitivity and color vision) and the total mercury (Lebel et al., 1996; Kim et al., 2012).

The effects of the organic mercury exposure on vision have been reported by investigations in fishery areas. Lebel et al. (1996) studied neurological functions in two riverine communities of Tapajós basin in the Brazilian Amazon. About the visual functions, they investigated the visual acuity, color vision, contrast sensitivity, and visual perimetry. They observed that the mercury hair of the sample ranged between 5.6 and 38.4 µg/g. They found little visual acuity and contrast sensitivity loss, but they reported color vision losses and a tendency towards visual field constriction in subjects with hair mercury concentrations of at least 20 µg/g. Rodrigues et al. (2007) measured chromatic and achromatic spatial tasks of mercury-exposed subjects. The sample of this study was composed of subjects with different exposure to the metal (total hair mercury concentration ranged between 14 and 47 µg/g). The subjects were Brazilian Amazonian gold-miners whose primary exposure to mercury was occupational, through the inhalation of mercury vapour. They probably also had environmental exposure from feeding off the fish because they lived in mercury-exposed riverine communities. The subjects also included riverine subjects from the Tapajós basin who had no contact with gold-mining activities but who had high hair mercury concentrations and were suspected of suffering methylmercury intoxication. They reported losses in both achromatic and chromatic vision. Kim et al. (2012) evaluated the relationship between mercury exposure and color vision loss in South Korean subjects (9–60 years old) living in fishery areas. They reported reduced color vision in 14% of the subjects. They found that the mercury levels in the blood, urine, and hair of subjects with color vision loss were higher than in subjects with normal color vision.

Gold-mining activity in the Amazon region of Brazil during the 1970s and 1980s released huge amounts of mercury into the rivers and atmosphere (Lacerda and Pfeiffer, 1992; Pfeiffer and Lacerda, 1988), which bioaccumulated in the food chain. The consumption of contaminated fish by riverside communities led to the accumulation of mercury within their bodies (Barbieri and Gardon,

2009). Riverside communities from the Tapajós river basins have been monitored for hair mercury levels by several groups of researchers (Akagi et al., 1995a,b; Barbosa et al., 1998; Dórea et al., 2012; Fillion et al., 2006; Hacon et al., 2000; Malm et al., 1995; Passos and Mergler, 2008; Pinheiro et al., 2006).

Children are vulnerable to mercury exposure due to its potential impact on their developing nervous system and other tissues (Counter and Buchanan, 2004). Two studies that were conducted 15 years apart demonstrated that children living in riverine communities in the Tapajós river basin maintained mercury exposure near the safety threshold indicated by the Joint Food and Agriculture Organization of the United Nations/World Health Organization expert committee on food additives (equivalent 2 µg/g of total mercury in the hair) (Grandjean et al., 1999; WHO, 2007; Marinho et al., 2014).

In the present study, we investigated the color vision of children living in riverine communities from the Tapajós river basin to investigate the impact of mercury exposure on the nervous system. We compared their results to those of children living in a riverine community from the Tocantins river basin, considered a mercury-free area.

2. Materials and methods

This is an exploratory ecological epidemiology study to investigate the association of total mercury concentration in the hair and the color vision of children living in riverine communities in the Brazilian Amazon. The research was conducted between August 2013 and July 2014 during four expedition trips of 10 days, two trips to each region. The trips to one region were followed by the trips to the other region. During this period, we recruited the participants and collected the data.

2.1. Subjects

One hundred and seventy-six children in the age group ranging from 7 to 14 years were studied. The present study was part of the Pro-Amazonia program of the Brazilian Federal Agency Coordination for the Improvement of Higher Education Personnel that aims to monitor the health and environment in the Brazilian Amazon.

We grouped the children according to the river basin where they lived: a mercury-exposed group from the Tapajós river basin, Barreiras community, 71 children, 31 males and 40 females, 11.25 ± 2 year-old, (GWS coordinates: $4^\circ 4'50''\text{S}$, $55^\circ 41'40''\text{W}$), and from the São Luiz do Tapajós community, 41 children, 26 male and 15 female, 10.13 ± 2 year-old (GWS coordinates: $4^\circ 26' 52'' \text{S}$, $49^\circ 23' 27'' \text{W}$), while the mercury non-exposed group was from Tocantins river basin, Limoeiro do Ajurú community, 64 children, 24 males and 40 females, 10.85 ± 2.1 year-old (GWS coordinates: $1^\circ 53' 56'' \text{S}$, $49^\circ 23' 27'' \text{W}$). All communities had similar lifestyles and diets consisting of high fish consumption. Mercury levels in the communities of the Tapajós basin have been continuously monitored over the last 23 years owing to the well-known contamination from gold mining activities in the upper Tapajós river basin (Akagi et al., 1995a,b; Akagi and Naganuma, 2000; Bidone et al., 1997; Castilhos et al., 1998; Malm et al., 1995; Pinheiro et al., 2000; Santos et al., 2000a,b). The investigated communities on the Tapajós river are away 355 km from the gold-mining area, and their inhabitants had no direct contact with the inorganic mercury, but the fish that accumulated the methylmercury in the region of the gold-mining area are hunted by the fishermen of these communities. There was no report of gold-mining activity near Limoeiro do Ajurú in the lower Tocantins river basin. Fig. 1 shows a map of the state of Pará, Brazil with the location of each riverine community indicated. Convenience sampling was done by personal invitation. The communities

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