Maternal mercury exposure and neuro-motor development in breastfed infants from Porto Velho (Amazon), Brazil

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Abstract

Fish is an important item in the diet of Amazonians, and per se is their best single source of essential nutrients. Rapid urbanization and migration are bringing changes in dietary habits of Amazonians. Exposure to fish-Hg during pregnancy and lactation were studied in 100 women and newborns from Porto Velho. Tissue-Hg concentrations and neurodevelopment (Gesell Developmental Schedules) were assessed at birth and at 6 months in exclusively breastfed infants. Maternal mean frequency of fish consumption was low (<2 meals/week; range 0–7 meals/week) compared to Amazonian standards. Women consuming <2 fish meals/week showed less median hair-Hg (3.5 mg g\textsuperscript{-1}) than women that consumed \geq 2 fish meals/week (5.7 mg g). Median total Hg in maternal hair (5.4 mg g\textsuperscript{-1}) was higher than in newborns (1.6 mg g\textsuperscript{-1}). Significant correlation was observed between maternal hair-Hg and infant hair-Hg at birth \((r = 0.353; p < 0.01)\) and at six months \((r = 0.510; p < 0.01)\). Placenta-Hg was also significantly correlated to maternal hair-Hg \((r = 0.321; p < 0.01)\), newborn hair-Hg \((r = 0.219; p < 0.05)\), maternal blood-Hg \((r = 0.250; p < 0.01)\) and to umbilical cord-Hg \((r = 0.857; p < 0.01)\). Most infants (74\%) had normal Gesell Schedules but among the 26\% showing neuro-motor development delays only six (7\%) had multiple (motor, language, and adaptative) delays. The infants with multiple delays were born from mothers with range of hair-Hg comparable to mothers of normally developed infants. Coincidentally, mothers of infants with multiple delays also showed the lowest range of income and level of education. Fish consumption, income, and level of education varied greatly among these breastfeeding urban mothers. It seems that development delays of exclusively breastfed infants are a component of the health inequalities that accompanies socioeconomic disadvantages.

Keywords: Amazon; Fish consumption; Neuro-motor development; Breastfeeding; Hair-Hg

Introduction

Mercury is listed among the most toxic substances in industrialized countries. One-third of emissions are estimated to originate from natural sources and the...
other two-thirds from anthropogenic sources (Patrick, 2002). Environmental Hg is found in various chemical forms: elemental Hg, inorganic Hg, and organic Hg (ethyl-, methyl-, alkyl-, or phenyl-Hg). The chemistry of Hg modulates its toxicity and metabolism. While inorganic Hg acts mainly on the kidneys, volatile metallic Hg and especially methylmercury (MeHg) primarily affect the central nervous system (CNS). The vulnerability of the developing human brain is the most important window for harmful Hg compounds (Castoldi et al., 2003). Dietary intake of fish and seafood products is the main source of MeHg exposure. Fish MeHg is easily absorbed by gastrointestinal tract and rapidly enters the blood stream. It is distributed throughout the body within 3–4 days. It is estimated that 5% of dietary MeHg is found in the blood and 10% in the brain, with a half-life ranging between 45 and 70 days (Castoldi et al., 2003).

Fish is an important item in the diet of Amazonians, and per se is their best source of essential nutrients. Fish is a fundamental complement for native Amazonians on protein-poor starchy food diets (70–80% of dietary energy from cassava); its protein content is well digested and has a high biological value (Dorea, 2004). Furthermore, besides its nutrient content, fish flesh can enhance absorption of Zn and Fe (Dorea, 2004). According to Inhamuns and Franco (2001), Amazonian fish contain omega-3 polyunsaturated fatty acids (PUFA; decosahexanoic [22:6] acid and eicosapentaenoic [20:5] acid) essential for infant neurodevelopment. Decosahexanoic acid is an essential component of nervous system cell membranes that is delivered to the fetus and post-natally into milk. However, fish is also a bioconcentrator of natural MeHg. Fortunately, Amazonian fish are, on the other hand, a good source of selenium (Dorea et al., 2003), known to counteract the toxic effects of Hg; significant correlations between Hg and Se in hair were reported in Amazonians (Vasconcellos et al., 2000; Campos et al., 2002).

A legitimate concern arising from the large amounts of metallic Hg (used to extract gold) discarded in the Amazonian environment prompted fish-Hg studies that were summarized by Dorea (2003). Amazon fish biococoncetrat MeHg originated from naturally occurring Hg in the rainforest (Barbosa et al., 2003). It is now known that Amazon soils are rich in Hg and those constitute a natural source of Hg for methylation (Fadini and Jardim, 2001; Bastos et al., 2006). However, while deforestation (along with agricultural projects) and alluvial-gold extraction have brought about vast changes in the environment of West-Amazonia, urban development has brought changes in the traditional lifestyles of human populations.

Fish consumption is part of the cultural adaptation of indigenous “ribeirinhos” (riverine populations). Amazonian women (especially Rio Negro ribeirinhos) depending heavily on fish consumption have showed hair-Hg that is among the highest of the world (Barbosa et al., 1998). Despite this no neurological problems involving fish consumption or other neurotoxic substance in foods like cassava products have been described (Dorea, 2004). Neuro-behavioral tests suggested that riverine children of East Amazonia presented alterations associated with high hair-Hg concentrations (Grandjean et al., 1999), but a recent study reported no significant difference (Tavares et al., 2005). In the French-Guyanese Amazon, Cordier et al. (2002) reported no major neurologic signs in Amerindian children of three different levels of fish-Hg exposure (regions with high, intermediate and low fish consumption). Nevertheless, but they observed that after adjusting for some potential confounders, there were dose-dependent (regions) effects, which were increased deep tendon reflexes, poor coordination of the legs, and decreased performance in the Stanford-Binet Copying score.

Tissue accumulation and toxicity are not equivalent in the case of Hg; MeHg accumulation is greater in the kidney than in the brain, but the brain appears to be the key target (Cory-Slechta, 2005). It is a point of fact that the CNS formation and development during pregnancy and lactation can be affected by multiple causes, ranging from maternal nutrition to neurotoxic-substance exposure. In this specific time window, Hg exposure can affect neurobehavioral functions. Mild exposure may result in delayed symptoms (not observed at birth), such as difficulty in walking and talking, and persistence of abnormal perinatal reflexes (World Health Organization (WHO), 1990; Myers and Davidson, 1998).

Our objectives were: (a) to study fish-Hg exposure of urban Amazonian mothers; (b) to associate maternal exposure (hair-Hg) with tissue-Hg and factors relevant to neuro-motor development of breastfed infants; and (c) to examine the association between generated dimensions of infant neurodevelopment and maternal socioeconomic and Hg exposure features.

Materials and methods

Porto Velho is the capital of the state of Rondonia (West Amazonia). Until the 1960s it was a traditional Amazonian city but after agricultural projects in the southwest region of the state followed the opening of roads, there was also a great influx of prospectors for exploring alluvial gold along the banks of the Rio Madeira basin. Since then, Porto Velho has experienced significant demographic changes with people coming from many other Brazilian regions.

The research protocol was approved by the Ethics Committee of Studies for Humans of the Universidade Federal de Rondonia. Pregnant mothers were introduced to the study and invited to participate by a nurse
during their routine visits to the Pre-natal Clinics of three hospitals of Porto Velho: Hospital de Base, Hospital Panamericano and Hospital Regina Pacis. Potential participants received plain-language information about the study and a written consent form was presented and signed by the volunteering mother; the written consent stated that participation was voluntary, their confidentiality was assured and that they could withdraw from the study at any time. Mothers were selected among those in good health, reporting no illness or complaints at the time of the study and who were willing to breast feed. Excluding factors were occupational exposure to toxic chemicals and hereditary neurological illnesses. One hundred mothers between the ages of 15 and 45 years were recruited among those that manifested the intention of exclusively breastfeeding up to 6 months of age.

For each mother a complete clinical evaluation was obtained from medical records and at the time of the first interview a questionnaire was applied to assess socioeconomic and educational status. The questionnaire also evaluated food habits, frequency of fish consumption, and intention of breastfeeding. While at the maternity wards, we collected samples of cord blood, placenta and hair from mothers and respective infants. The newborns were clinically examined with special attention to vitality, perinatal reflexes, maturity, and congenital malformations; weight, length, head circumference, and Apgar scores were recorded. Anthropometric data at birth (weight, length and head circumference) were compared with data tabulated by the ANTHRO 1.02, 1999 software for calculating pediatric anthropometry (Centers for Diseases Control and Prevention was used). The software for calculating pediatric anthropometry (ANTHRO 1.02, 1999) from the Centers for Diseases Control and Prevention was used.

At 6 months of age, only 86 of the 100 original mother–infant pairs reported for the programmed clinical and neurobehavioral examination when hair samples were collected again. Five mothers had moved out of the state, five did not report and could not be found, and four babies had died within the first month. Because two mothers developed gestational diabetes and two others developed pre-eclamptic toxemia, we used only data from 82 mother–infant pairs. Children received the full immunization scheme in accordance with Brazilian vaccination program.

The infants' development assessment was conducted at the age of 6 months by trained professionals using the Gesell Developmental Schedules (Gesell, 2003; Gesell and Amatruda, 2000). The Gesell Schedules included all reactions (voluntary, spontaneous or learned) and reflexes. We also evaluated postural reactions, hand pressure, locomotion and coordination, constructive ability (which is influenced by motor development), visible and audible communication, individual reactions regarding people and stimulations (depending mainly on the temperament of the child and the surroundings). The results were expressed as developmental scores for the Motor Skills, Language Development, Adaptive Behavior, and Personal Social behaviors.

**Hg determination**

Sample preparation and Hg determination were done according to routine procedures previously established at the Universidade Federal do Rio de Janeiro (Bastos et al., 1998). We followed routine procedures of the laboratory after adaptation of analytical protocol used for Hg determination in previous studies analyzing blood, hair and fish-flesh matrices (Bastos et al., 1998; Malm et al., 1989, 1998). Briefly, the hair samples were comminuted with stainless steel scissors, weighed, and digested before analysis. Blood samples were digested with concentrated HNO$_3$ (3 mL) and KMnO$_4$ (5%; 6 mL) using a microwave oven system for 35 min (CEM Corporation, MDS 2000, Matthews, NC, USA). Placenta and umbilical cord samples were weighed and digested with HNO$_3$:H$_2$SO$_4$ (1:1; 5 mL) and KMnO$_4$ (5%; 4 mL) using a digestion block at 80°C for 1 h (Tecnal Ltd., Piracicaba, São Paulo, Brazil). Human hair samples were washed with EDTA 0.01%, dried in an oven at 50°C, weighed and digested with 5 mL of HNO$_3$:H$_2$SO$_4$ (1:1) and 4 mL of 5% KMnO$_4$ using a digestion block at 80°C for 40 min. The determination of total Hg in the digested samples was done by cold vapor atomic absorption spectrometry with a flow injection system-FIMS (CV-AAS, Perkin-Elmer—FIMS 400, Ueberlingen, Germany). All glassware used in the analytical protocol was washed clean, rinsed with 5% EDTA and double distilled, and left to rest in 5% HNO$_3$ overnight. Then it was rinsed again in double-distilled water, and dried at 100°C for 12 h. Precision and accuracy of Hg determinations were assured by the use of internal standards, use of triplicate analyses of samples and certified reference materials (IAEA-085 and 086, Vienna, Austria) with recoveries of 92%.

**Statistical analysis**

A multivariate correspondence model was used to analyze maternal factors (tissue Hg, socio-economic...
status) that might affect the infant’s social and adaptive abilities, gross motor ability or the fine motor ability; this step was done with statistical software (Statsoft, 2002, Tulsa, AZ, USA). Variables used for the analysis are listed in Table 1. Afterwards, correlation analysis was used to compare the tissue-Hg concentrations between mothers and respective neonates (SPSS for Windows 14.0, 2005, Chicago, USA).

Results

Descriptive data of mothers and infants are presented in Tables 1–5. The demographics summarized in Table 1 show a wide range of socioeconomic status (SES). Most of the 100 mothers were enrolled from a public hospital (n = 61, Hospital de Base) while 39% were from corporate middle-class hospitals (n = 13, Hospital Panamericano; n = 26, Hospital Regina Pacis); a substantial proportion (39%) of these mothers were primiparas. The median income was US$125, and 64% did not have indoor plumbing, thus indicating that the majority of mothers were socioeconomically underprivileged. Irrespective of income and education, 57% reported that they consumed fish up to once a week, 4% reported more than 7 fish servings a week and only 5% reported not consuming fish (Table 1). Anthropometric data of mothers and infants are shown in Table 2. Nine newborns were below and two were above NCHS reference curves for weight. After 6 months of exclusive breastfeeding four children were overweight and only three boys presented short length.

Mercury exposure data are presented in Tables 3–5. Tissue Hg concentrations as a function of reported

| Table 1. Socioeconomic characteristics of the 100 mothers enrolled in the study |
|---------------------------------|------------|----------|-------------|
| Characteristics                | Minimum    | Median   | Maximum     | Percentage  |
| Mother education (years)       | 0          | 8        | 18          |            |
| Income (US$/m)                 | 16.67      | 125.00   | 1250.00     |            |
| Type of home                   |            |          |             |            |
| Owned                          |            |          |             | 57         |
| Rental                         |            |          |             | 14         |
| Living with relatives          |            |          |             | 29         |
| Persons/household              | 2          | 5        | 14          |            |
| No electricity                 |            |          |             | 20         |
| Water supply                   |            |          |             |            |
| Running water                  |            |          |             | 36         |
| Well                           |            |          |             | 61         |
| Local rivers                   |            |          |             | 3          |
| Fish-eating habits             |            |          |             |            |
| Fish meals (week)              | 0          | 1        | 14          |            |
| 0–1/week                       |            |          |             | 57         |
| 2–7/week                       |            |          |             | 43         |
| Fish-eating sources            |            |          |             |            |
| Market fish                    |            |          |             | 53         |
| Local rivers                   |            |          |             | 42         |
| No fish                        |            |          |             | 5          |

*Primiparas = 39.
frequency of fish consumption are shown in Table 3. In this study, maternal fish consumption (hair-Hg) did not depend on monthly income or years of education; mean income and education were very close between the groups. The maternal hair-Hg concentrations varied widely (0.2–62.4 μg g⁻¹) reflecting extremes of reported fish consumption. Indeed mothers that reported low fish-consumption (<2 servings a week) showed a lower median hair-Hg concentrations (3.5 μg g⁻¹) than the other group (5.7 μg g⁻¹). Most of the maternal hair-Hg concentrations (57%) were below 6 μg g⁻¹; 34% of hair samples showed Hg concentrations between 6 and 15 μg g⁻¹ and 9% showed hair-Hg greater than 15 μg g⁻¹. The statistics of Hg concentrations in mothers and infants are shown in Table 4. The median umbilical cord-Hg concentration (7.5 ng g⁻¹) was close to the median placenta-Hg concentration. Fetal hair-Hg of the 82 newborns showed that 92% were <6 μg g⁻¹; 7% were between 6 and 15 μg g⁻¹ and only 1% was >15 μg g⁻¹. Correlation coefficients among maternal and infant Hg-variables are summarized as follows: significant non-parametric correlations (Spermans) were observed between maternal hair-Hg and infant hair-Hg at birth (r = 0.353; p < 0.01) and at 6 months (r = 0.510; p < 0.01). Placenta-Hg was also significantly correlated with maternal hair-Hg (r = 0.321; p < 0.01), newborn hair-Hg (r = 0.219; p < 0.05), maternal blood-Hg (r = 0.250; p < 0.05), and with umbilical cord-Hg (r = 0.857; p < 0.01).

The assessment of neuro-motor development of breastfed 6-month-old infants is summarized in Table 5. Most infants (74%) showed normal schedules and 21 children (26%) exhibited developmental delay in one or more features of the Gesell Schedules: 1% showed motor impairment, 9% had language deficits, and 16% had multiple impairments (7% motor, language, adaptive, and 9% motor, language). There were no children who presented developmental delay in the personal social behavior. There were no children who presented developmental delay in the social ability. The 26% of infants showing neuromotor delays showed higher median hair-Hg values; these infants were born from mothers that had median hair-Hg concentrations also higher than mothers of normally developed infants. However, infants with multiple delays were born from mothers that also showed the lowest median income. The infants with higher median fetal hair-Hg showed even higher median hair-Hg at 6 months (Table 5).

Multivariate analysis was performed to identify groups of related variables. After identification (and removal) of redundant variables by Cluster Analysis, Correspondence Analysis was applied to identify groups of associated variables. Association (co-occurrence) is characterized by similar position in the two-dimensional (2D) plane depicted in Fig. 1. The first dimension is characterized by the infant groups which showed the most delayed development (adaptive, motor and language) and the greatest hair-Hg concentrations (group #1 and group #3). In contrast with a group of normal children from high income families and more educated mothers (group #2). The second dimension is mainly characterized by the highly exposed neonates (group #1, with high hair-Hg) in contrast with another group of infants with mild delay in Gessel scores (group #4).

**Discussion**

Assuming that hair strands are the best integrator of past MeHg exposure, the main finding of this study is that the marker of fish consumption (maternal hair-Hg) significantly correlated with fetal hair-Hg; this significant association lasted until 6 months of lactation. Notably, delay in neuromotor development observed in infants with higher median hair-Hg did not indicate a dose response relationship: the highest hair-Hg values were found in the normal infant group (Table 5).
In Fig. 1, the highest income and educational levels were clustered in group #2. These findings suggest the occurrence of some protective conditions which were not present in underprivileged families. Poorer and less educated families more probably lack mother–fetus pairs ideal development support.

The mean hair-Hg of these mothers (7.4 μg g⁻¹) is lower than reported values for ribeirinho mothers (8.3–9.4 μg g⁻¹) of the Rio Tapajós (Pinheiro et al., 2005), breastfeeding mothers (14.3 μg g⁻¹) of the Rio Madeira (Barbosa et al., 1997) and the Rio Negro (Dorea et al., 2003). In the ribeirinho women of the Rio Madeira, the mean breastmilk-Hg concentration was 5.8 ng g⁻¹ and infant hair-Hg was 9.8 μg g⁻¹ (Barbosa et al., 1997). There were indications that MeHg transfer was higher during pregnancy than during breastfeeding. Nevertheless, there are no reports of clinical signs of neuropathologies in that population associated with fish consumption. A recent study of urban mothers from Paramaribo (Surinamese Amazon) showed a much lower concentration (0.8 μg g⁻¹) of hair-Hg (Mohan et al., 2005). In non-traditional urban pregnant-women of Alta Floresta (southern Amazonia) the mean hair-Hg concentrations was also 1.2 μg g⁻¹ (range, 0.05–8.2 μg g⁻¹).

### Table 5. Frequency distribution of neurodevelopment (Gesell Schedules) of infants at 6 months of age and summary of corresponding markers of Hg exposure and socioeconomic status

<table>
<thead>
<tr>
<th>Gesell Scale</th>
<th>N [%]</th>
<th>Infant hair Hg, 0m (μg g⁻¹)</th>
<th>Infant hair Hg, 6m (μg g⁻¹)</th>
<th>Mother hair Hg (μg g⁻¹)</th>
<th>Income (US$)</th>
<th>Mother education (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>61 [74]</td>
<td>1.4 (0.05–9.3)</td>
<td>1.6 (0.01–33)</td>
<td>4.28 (0.39–62.43)</td>
<td>145.8 (16.7–1250)</td>
<td>8 (4–18)</td>
</tr>
<tr>
<td>Motor (M)</td>
<td>1 [1]</td>
<td>0.62</td>
<td>1.7</td>
<td>10.56</td>
<td>375</td>
<td>11</td>
</tr>
<tr>
<td>Language (L)</td>
<td>7 [9]</td>
<td>1.59 (0.3–3.5)</td>
<td>2.8 (0.9–26.9)</td>
<td>7.29 (1.3–28.73)</td>
<td>145.8 (50–525)</td>
<td>8 (5–16)</td>
</tr>
<tr>
<td>M and L</td>
<td>7 [9]</td>
<td>2.3 (0.6–7.4)</td>
<td>5.6 (1.2–15.1)</td>
<td>10.34 (2.1–12.48)</td>
<td>104.16 (70–125)</td>
<td>8 (4–11)</td>
</tr>
<tr>
<td>M, L and Aa</td>
<td>6 [7]</td>
<td>6.4 (2.3–19.7)</td>
<td>6.9 (0.4–18.1)</td>
<td>5.74 (3.2–20.77)</td>
<td>104.16 (83.3–208.3)</td>
<td>6.5 (6–11)</td>
</tr>
<tr>
<td>Overall</td>
<td>82 [100]</td>
<td>1.6 (0.05–19.7)</td>
<td>1.8 (0.02–33)</td>
<td>5.40 (0.39–62.43)</td>
<td>125 (16.7–1250)</td>
<td>8 (0–18)</td>
</tr>
</tbody>
</table>

Median (Min–Max); m = month; y = year.

*A = Adaptive.

![Fig. 1. Multivariate analysis (anthropometrics parameter, performance in Gesell schedule and socioeconomic status). MT—Motor, LG—Language, AD—Adaptive, N—Normal, D—Delay, L—Borderline, If—infant Hg-hair, Nn—newborn Hg-hair, ySch—mother education in year, $—income, WL—weight-for-length percentile.](image-url)
This population is formed by non-fish eaters that migrated from the South of Brazil during the gold rush (Hacon et al., 2000). The studied sample of Porto Velho women is not homogenous, neither culturally or socioeconomically. Therefore, because there were no severe prenatal insults that could distort early pattern of neurodevelopment, the observed delays were within expected rates for Brazilians (Paine and Pasquali, 1983). Even in homogenous populations there are variations in neurobehavioral outcomes. Dodge et al. (1975) have discussed the limitations of the reliability of a single function as the evaluator of an insult. In our case there were only six cases of retardation of all milestones.

Regarding prenatal Hg exposure, our results (Gesell Schedules) are consistent with the absence of neurodevelopmental abnormalities in early childhood reported in Peruvian mothers (Pacific coast) with comparable mean hair-Hg levels (8.3 μg g⁻¹; range 1.2–30 μg g⁻¹) during pregnancy (Marsh et al., 1995). A larger longitudinal study with 708 Seychellois infants also reported that in utero exposure to MeHg (from a maternal fish diet) caused no adverse outcomes in neurological and psychological development at 6 months of age (Myers et al., 1995). In that study maternal hair-Hg ranged from 0.5 to 26.7 μg g⁻¹ (Myers et al., 1995). Neurodevelopmental and Hg-associated studies of infants and young children sometimes do not make references to breastfeeding status. Because of the fundamental role of breastfeeding and neuromotor development it is important to emphasize such studies. Only 6% of the breastfed infants in the present study showed adaptive behavior delays. Specific components (PUFA) present in breast milk, but not in infant formulas, which are essential for neuronal development and organization have accounted for cognitive and developmental scores in favor of breastfeeding (Agostoni et al., 2001).

Therefore, when breastfeeding is considered in maternal-Hg contamination studies, there are clearly benefits for the neurodevelopment of the breastfed infants (Grandjean et al., 1994; Jensen et al., 2005).

Although we collected fetal hair at birth, infant exposure to maternal Hg (consumed as fish-MeHg) during pregnancy is better assessed with maternal hair-Hg. Indeed, maternal hair-Hg was significantly correlated with fetal hair-Hg, which is in agreement with other Amazonian studies of women with high (Barbosa and Dórea, 1998) and low (Mohan et al., 2005) fish consumption. Lindow et al. (2003) also found significant correlation between maternal hair-Hg and fetal hair-Hg in a group of mothers predominantly exposed to dental amalgam-Hg. There are several drawbacks in fetal hair-Hg as a reliable indicator of intra-uterine exposure. Not all infants are born with hair; hair starts to grow at the 18–20th week of development at the frontal and the parietal regions and is likely to fall by the time of birth. Also, occipital hair is likely to grow at the time of birth and to fall after 12 weeks. Furthermore, hair density, length and texture are dependent upon factors such as race and sex. Fetal hair-Hg in the present study was higher (2.4 μg g⁻¹) than for newborns (1.6 μg g⁻¹) of urban Surinamese mothers (Mohan et al., 2005).

Studies involving non-occupational maternal Hg exposure (fish consumption) during pregnancy and infant neuro-motor development are complicate to design because of the confounding factors. This is further complicated when mothers are exposed to neurotoxic substances other than MeHg present in fish (Stewart et al., 2003). Nevertheless, maternal fish intake during pregnancy was associated with higher developmental scores for language comprehension, and social activities (Daniels et al., 2004). A recent study by Oken et al. (2005) in low fish-eating American mothers showed that the mean visual recognition memory was higher at six months in infants born to mothers that ate > 2 fish servings/week but had less than 1.2 of hair-Hg during pregnancy, clearly suggesting an interaction between positive effects of fish eating and negative effects of Hg contamination. Although the multivariate model adjusted for breastfeeding duration, Oken et al. (2005) failed to address the organic Hg effects currently debated in vaccinated infants.

Fetal Hg exposure is exclusively derived from maternal contamination. However, during breastfeeding, iatrogenic Hg exposure (vaccines) is frequent but has not been taken into consideration in infant neurodevelopmental studies. Redwood et al. (2001) reviewed Hg exposure due to Thimerosal (Thiomersal, ethylmercurithiosalicate-TMS), a preservative found in many infant vaccines. TMS contains 49.6% ethyl mercury-EtHg (by weight) contributing 25 μg of EtHg per dose; 12.5–40% depending on the vaccine (Redwood et al., 2001). During an immunization schedule, infants may receive vaccines at birth (12.5 μg EtHg), two (62.5 μg EtHg), four (50 μg EtHg) and six (62.5 μg EtHg) months that could expose them to a total of 207.5 μg EtHg during the first 6 months of life. The possible association of vaccinations (containing TMS) and autism spectrum disorders (ASD) is gaining scientific attention. Mutter et al. (2004, 2005) discussed the epidemiology and mechanism of Hg-associated developmental (behavioral) disorders and suggested that effects of MeHg found in fish are less toxic compared to iatrogenic sources of Hg. They argued that the vaccine situation resembles the epidemic of acrodynia in the last century which affected up to 1 of 500 infants. After removing teething powder, which contained Hg as calomel (Hg₂Cl₂), acrodynia disappeared. They also argued that in 1953 immunizations with TMS-containing vaccines preceded the onset of acrodynia in several cases. It should be noticed that epidemiological studies relating ASD and vaccine-TMS have not considered...
breastfeeding. However, there is one study indicating that early weaning could contribute to the etiology of autism (Tanoue and Oda, 1989).

Mercury in the umbilical cord is not frequently assessed, but one such study (Murata et al., 2004) reported that maternal hair-Hg concentration was significantly correlated with the MeHg in the umbilical cord obtained from 49 newborns. This is closely in line with our present study. Besides easier sampling and processing, umbilical cord may be collected 1 week after birth. A retrospective study (babies born between 1950 and 1965) of the Minamata crisis in Japan showed that the 24 patients diagnosed with Minamata disease had umbilical cord Hg concentrations of 1.63 μg g⁻¹ (Akagi et al., 1998). This is higher than values that we (in the present study) and others (Daniels et al., 2004) found in low fish eating mothers.

Although fish consumption has been monitored for riverine populations this is the first study reporting fish consumption of urban Amazonian mothers. In Amazonian populations hair-Hg is a surrogate of fish consumption of urban Amazonian mothers (Franco et al., 2005a) and children (Dorea et al., 2005b). The Brazilian Amazon population showing elevated hair-Hg exposure is mainly indigenous and ribeirinho. The importance of subsistence fishing for ribeirinho communities has shown to be proportional to their distance from urban centers (Alves et al., 2006). In remote communities of the Rio Madeira subsistence on fish is also well characterized by mean hair-Hg concentrations >16 μg g⁻¹. We recently showed that these communities may consume fish twice a day (Bastos et al., 2005). In the present study, fish consumption of the Porto Velho mothers is greatly decreased probably as a result of urbanization and migratory fluxes from other parts of the country. However, hair-Hg is much higher than in Paramaribo women (Mohan et al., 2005). This study also shows that neuro-motor development is not associated with fish consumption but could be placed with health inequalities and social deprivation. Indeed, Cory-Slechta (2005) discussed low SES itself as a known risk factor for adverse health outcomes and behavioral dysfunctions both in adults and children. Low SES is associated with higher levels of mental retardation, learning disorders and language and attention deficits in children. Rice (2005) argued that the higher incidence of disease and dysfunction accompanying low SES is due to the greater environmental stresses experienced by such populations: a chronic strain associated with persistent economic hardships resulting in protracted elevation of cortisol levels.

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