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FOOD RISK AND SEA-FOOD CONSUMPTION: EVALUATION OF LONG-TERM INDIVIDUAL EXPOSURE TO METHYLMERCURY IN FRANCE

Prolonged exposure to methylmercury, mainly present in sea-food products (fish, mollusks and shellfish) produces deep neurotoxic effects. The main purpose of this study is to quantify this risk for French consumers using consumption and contamination data. French consumers likely to be strongly and lastingly exposed to this contaminant are identified according to their age, sex and socio-economical characteristics, so that adapted recommendations to at-risk consumers may be taken. For 2001, we estimate that 6% of children under 3 are high-risk individuals. Furthermore, no children living in a low income household are high-risk consumers.

Introduction

The quantitative assessment of dietary exposure to contaminants has been one of the Food and Agricultural Organisation and World Health Organisation (FAO/WHO) priorities since 1997. FAO/WHO attention is specifically directed towards dietary exposure to methylmercury, mainly present in sea-food products (fish, mollusks and shellfish). Excessive and long exposure to methylmercury may have neurotoxic effects such as neuronal loss, ataxia, visual disturbances, impaired hearing, and paralysis (FAO/WHO, 2003). These risks are extremely high for nervous systems in development (foetuses, babies). An assessment of exposure to methylmercury is all the more necessary in that, since June 2003, FAO/WHO experts have reduced the Provisional Tolerable Weekly Intake (PTWI) for methylmercury. Thus, PTWI for the human organism is now fixed at 1.6 µg per kilogram of body weight per week, given that FAO/WHO measured an average quantity of 1mg of methylmercury for a kilogram of predatory fish (tuna, swordfish, ray) and 0.5 mg of methylmercury for one kilogram of all other sorts of fish. As an illustration, for constant body weight, a child weighing 20 kg who eats more than 320 gr of predatory fish every week and an adult of 55 kg who eats more than 880 gr of predatory fish every week are above the PTWI. This tolerable intake is fixed for a whole life: an individual whose exposure to methylmercury is superior to 1.6 µg per kilogram of body weight for each week of his life is a high-risk individual for FAO/WHO. The risk is all the more marked in that the elimination of methylmercury from the body is very slow. The major problem is to quantify exposure over an entire life or to determine consumers' sea-food consumption habits, supposing that the food contamination is steady.

In general, an assessment of exposure to methylmercury relies on an estimation of the probability of exceeding the PTWI. In this way, Tressou and *al*. (2004) and Bertail and Tressou (2005) compare short-term exposures (one week) to the PTWI, defined for a whole life. The probability of exceeding the PTWI must be perceived more as a risk indicator than as a real measure of the risk. The purpose of this survey is to provide a real risk measure of contamination to methylmercury by assessing French consumers' long-term exposure to methylmercury according to their age, sex and socio-economical characteristics so that adapted recommendations may possibly be issued to high-risk consumers.

From total household exposure to estimated individual exposure

Assessing long-term individual exposure to methylmercury requires both a database that provides the quantity of fish and seafood consumed over a long period of time, and contamination data for these sea products. The level of exposure to a contaminant is the consumption amount of every contaminated food weighted by the corresponding contaminant average level of contamination (frame 1). Unfortunately, in France there is no database recording the individual sea-food consumptions over a long period of time. The SECODIP database (Boizot, 2005, for a presentation of this data), by its longitudinal character, helps follow the evolution of consumption behaviours over time; each household stays in the sample for four years, on average. However, its use in a food risk exposure assessment is problematic:

i) SECODIP does not record the amounts consumed or the amounts destined for a particular member of the household. Thus it is impossible to assess individual dietary exposure to a contaminant using this database. The calculation of the exposure level to MeHg can only be made at the household level,

ii) SECODIP does not provide any information on the quantities of fish and seafood products consumed out of home,

iii) SECODIP provides the amount of food bought by the households, which may be different from the amount actually consumed,

iv) Until 2001 SECODIP did not provide information on the body weight of the individuals, an item which is necessary to calculate individual exposure.

Problem (i) is addressed by using a statistical method that estimates individual quantities when households' composition and household quantities are observed, presented in Allais and Tressou (2005). In this way, SECODIP records the sea-food product purchases of 3,214 households, which represent a total of 9,261 individuals. Each household's exposure to MeHg is deduced from these purchases. Then, the 9,261 individual exposure levels to MeHg are assessed through that method, by introducing 4 socio-economical variables:

- the category of income, numbered from 1 (the well-to-do) to 4 (the modest),
- the region of residence by distinguishing coastal and non-coastal departments
- the education level of the household head,
- the household head's socio-professional category (SPC).

Problem (ii) is a traditional problem with household purchase data; however, this data is acknowledged as a good approximation of total household consumption. Nevertheless, auxiliary information about outdoor consumption could be introduced into the model as a correction factor accounting for outdoor consumption propensity according to age, sex or socioeconomic variables. This factor could probably be estimated using the INCA (National survey on individual food consumption in France, CREDOC AFSSA-DGAL, 1999), which gives details about at home / outdoor consumption but only for people aged 3 and older. However, children of under three years are potentially the most sensitive and vulnerable to the neurotoxic effects of methylmercury. Considering this lack of information, no correction factor is introduced into the model and our assessment of dietary exposure to methylmercury is carried out for fish and seafood products consumed at home.

Problem (iii) is characteristic of consumption data. An appreciable part of fish or sea-food product is not edible. From the general food repertory (CIQUAL 1995), the average edible proportion, calculated from the 25 most consumed fishes in France, is estimated at 61% of the gross weight of fresh or deep-frozen fish. A correction of this problem would involve reducing the consumed part of fish and sea-food products and then reducing consumers' exposure to MeHg, already under-estimated because consumptions outside the home are not taken into account. Moreover, SECODIP does not specify whether the quantity of purchased fresh or deep-frozen fish is ready-to-be-consumed (in fillets) or in the form of a whole fish. Bearing in mind this lack of information on the preparation of fresh or deep-frozen fish, no edible proportion factor is introduced into this study.

Problem (iv) is resolved using average body weights by age and sex, calculated from the INCA survey for adults, and usual curves of average weight for consumers under 18 years old.

In the assessment of exposure to MeHg, the SECODIP survey confronts us with one further problem. SECODIP does not document the fish species purchased fresh, while the MeHg concentrations contained in fish species at the end of the food chain are much higher than the ones contained in fish species at the beginning of the food chain: The calculation of exposure to MeHg is made from the average concentration of MeHg in fish (see frame 1). This problem also exists for mollusks and shellfish, but is quantitatively unimportant considering the low concentrations of MeHg in them.

The purpose of this analysis is to determine long-term individual exposure, estimated by the sum of the individual weekly exposures over at least 36 consecutive weeks, weighted by a dissipation factor representing the natural elimination of methylmercury from the body. The estimation of the weekly individual cumulative exposure is presented in frame 2.

Results

Assessment of the annual individual exposure to MeHg

Firstly, the annual exposures to MeHg of the 9,261 individuals are estimated from total annual exposures to MeHg, calculated from the purchased quantities of sea-food products in the course of 2001. These individual exposure assessments will help us specify the pertinent socio-economical variables to estimate long-term individual exposures to MeHg.

The study of the significance of socio-economical variables shows that the education level and the socio-professional category of the head of the household do not explain annual individual exposure and that the region of residence modalities of "northern coastal departments", "Paris and suburbs" and "non coastal departments" may be grouped together. The region of residence variable is thus composed of 4 modalities: the new modality, "western coastal departments"; "south-western coastal departments"; "Mediterranean coastal departments" (respectively "area 1" to "area 4"). The indicators of income category are strongly significant.

Secondly, the hypothesis of dependence of the individual exposures within the household, and of identical functions of individual exposures according to sex is tested through likelihood ratio tests (LR). The hypothesis of independence of the individual exposures within the household is strongly rejected. Allais and Tressou (2005) show that wrongly accepting the hypothesis of independence of the individual exposures within the household leads to under-estimating the exposure to MeHg for children from 0 to 20 years old and for persons from 70 to 90 years old. Yet, for other age brackets, exposure to MeHg is relatively over-estimated in case individual consumptions are correlated in the household. Furthermore, the functions of individual exposure are significantly different according to sex. The model, in which socio-economical variables are the indicators of income class (4 modalities) and of region of residence (4 modalities) and in which individual exposures are correlated in the household with different functions of individual exposure according to sex, is thus retained.

Graph (1) represents the mean individual exposure to MeHg of men in mg/year, according to age and region of residence. The mean individual exposures are almost identical in "western coastal departments" and in "Mediterranean coastal departments", irrespective of sex. Moreover, "south western coastal departments" present the highest mean exposures and the individuals living in "Paris and suburbs, northern coastal and non coastal departments" are the least exposed to MeHg. Women's average individual exposure curve profiles are very close to men's. However, the contamination peak is reached at the age of 70 for women against 66 for men.

In graph (2) the mean individual exposure to MeHg of men is represented according to age and income class. The higher the household income class, the stronger the individual exposure to MeHg. This last result is also true for women whose mean individual exposure curve profiles, according to income, are very close to men's.

Assessment of long-term individual exposure to MeHg

In this section, we estimate French consumers' cumulated individual exposures to MeHg over each week of 2001. Firstly, weekly individual exposures are assessed from the weekly household exposure and from every household composition during 2001. As before, individual exposures in a household are supposed to be correlated; individual exposure functions are supposed to be different according to sex. Secondly, long-term or cumulated individual exposures in each week of 2001 are deduced (see frame 2) by taking into account the very slow elimination of MeHg from the body.

In graph (3) the evolution of some people's individual exposures to MeHg are represented over the 52 weeks of 2001 in µg per kilogram of body weight. These people were chosen according to their average level of individual exposure over the year: we retained certain distribution quantiles of non-zero average individual exposures (P50, P75, P95, P99, P99.9, max). In this way, the P50 curve represents the evolution of the cumulated individual exposure to MeHg for the individual mean annual exposure equal the median non-zero mean annual exposure. These weekly levels of cumulated individual exposures are compared with a reference individual whose weekly exposure to MeHg would be equal to the PTWI defined by FAO/WHO (full curve with stars). In graph (3), we see that the long term individual exposure is reached at the 22^{nd} week for 75% of the individuals and at the 32^{nd} week for 99% of the people. A very small number of people are situated over the reference curve. We assess that 2.2 individuals out of 1000 are high-risk and all these high-risk people are children under 3 years old; that is to say, 6% of the age bracket of children under 3 run the risk of contamination by MeHg. Moreover, children under one represent 72% of high-risk children. Thus, in graph (3), the individual at the 99.9 quantile of distribution of the mean exposures is a girl less than one year old living in a household with an income class over the average (class 2) and whose living area is "south-western departments". Furthermore, we assess that lower-income class individuals never reach cumulated exposure levels superior to those of the reference cumulated exposure. Lastly, we assess that 59% of children whose exposure is higher than the reference are children living in the non coastal departments, northern coastal departments or in Paris and suburbs.

FAO/WHO considers that the risk of contamination to MeHg is extreme for nervous systems in development (foetuses, babies). It would appear desirable to make parents of children under three aware of that risk of contamination.

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Frame 1: Calculation of exposure to MeHg

MeHg exposure, quoted D, is given by

$$D = \sum_{p=1}^{2} \overline{q}_p c_p$$

Where c_p is the consumption of sea product *p* expressed in kilograms and $\overline{q}_p$ is the mean contamination level of this sea product. These mean contamination levels were estimated from series of analyses in fish and seafood carried out by French administrations (MAAPAR, 1998-2002 ; IFREMER, 1994-1998). The mean contamination levels are 0.147 mg/kg for fish (*p=1*) and 0.014 mg/kg for mollusks and shellfish (*p=2*).

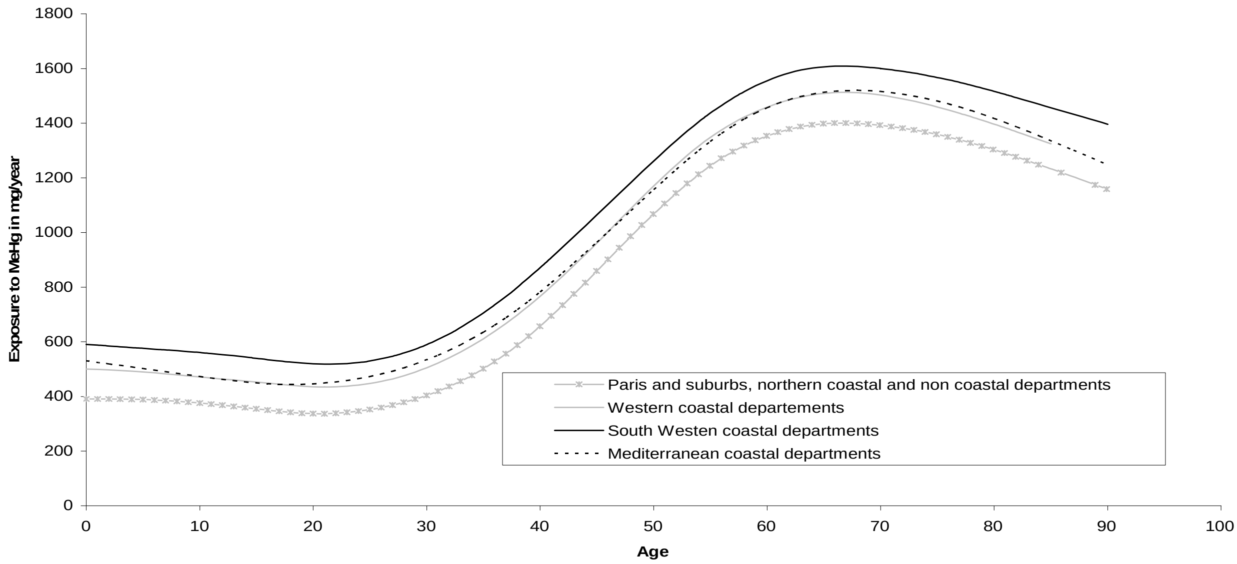
Frame 2: Calculation of cumulated exposure

Cumulated exposure to MeHg of an individual *i* belonging to the household *h* for the week *t*, quoted $S_{i,h,t}$, is

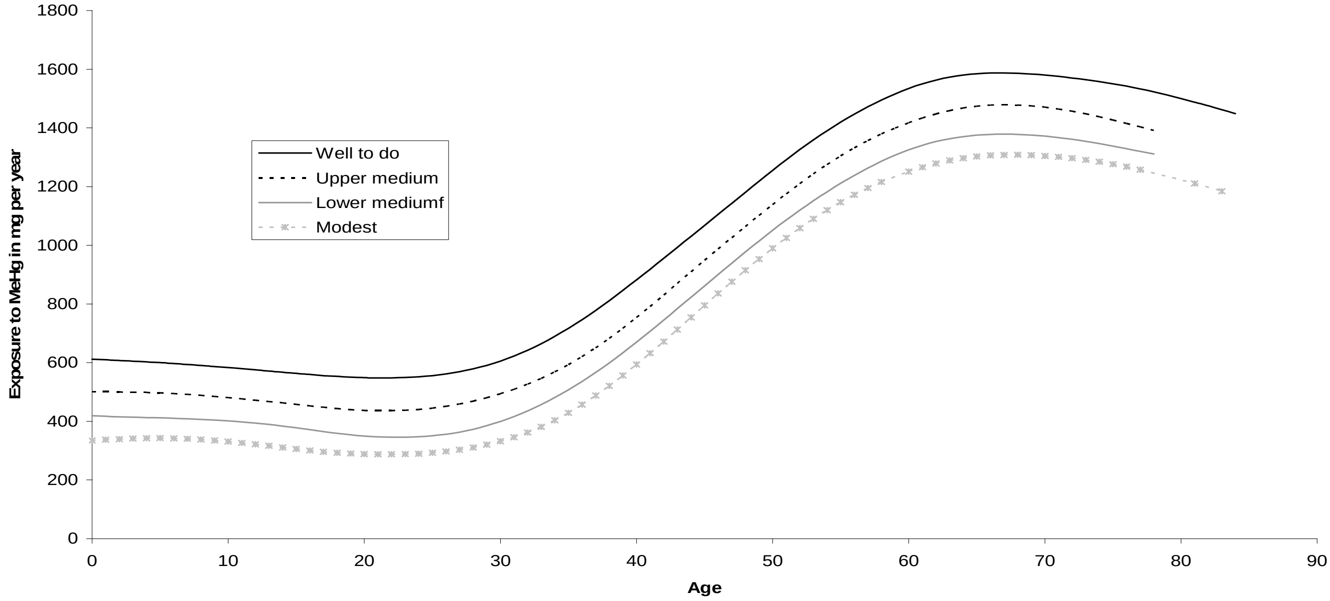
$$S_{i,h,t} = \exp(-\eta) S_{i,h,t-1} + D_{i,h,t},$$

where $D_{i,h,t}$ is the assessed exposure of an individual *i* of the household *h* of the week *t* and η the elimination rate of MeHg in the human body, fixed at *–ln(0.5)/6*. Smith and Farris (1996) evaluate that 6 weeks are necessary for a quantity of MeHg to reduce by half in the human body. Thus, if an individual has a level of exposure S_0 at week 0 and does not eat any sea products during the following 6 weeks, his cumulated exposure by week 6 is given by $S_6 = \exp(-6\eta) S_0 = S_0 / 2$. The initial value of this series for an individual *i* is equal to the average of his exposures $D_{i,h,t}$ over the observation period.

Graph 1 – Mean annual exposures to MeHg for men according to age and region of residence



Graph 2 – Mean annual exposure to MeHg for men according to age and income category



Graph 3 – Evolution of the cumulated individual exposure