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Methylmercury in fish and seafood – health risk assessment of new data from the BfR MEAL study

The risk of health impairments due to the presence of methylmercury in fish and seafood can be reduced by selecting species with low concentrations. Comparatively high concentrations of methylmercury are measured in tuna and ocean perch. Unborn children and infants are particularly sensitive to health impairments caused by the intake of methylmercury, as methylmercury can disrupt neurological development. It is therefore advisable for pregnant and breastfeeding women in particular to choose species that contain lower levels of this undesirable substance.

According to the evaluation of scientific data, the German Federal Institute for Risk Assessment (BfR) does not see any significant health risks for most people in Germany from methylmercury intake through the consumption of fish or seafood: With an average consumption of these foods, the amount of methylmercury ingested in all age groups is below the tolerable weekly intake (TWI) of 1.3 micrograms (µg) of methylmercury per kilogram of body weight per week. This value was derived by the European Food Safety Authority (EFSA).

The current assessment by the BfR is based on data from the BfR MEAL study (Meals for Exposure Assessment and Analysis of Foods). With this study, the BfR is analysing for the first time in Germany on a large scale which substances are contained in prepared foods and in what amount. Specifically, measurements of methylmercury levels in ready-to-eat fish and seafood, such as smoked salmon or fish fingers, were included in the health risk assessment. These were combined with data on the consumption of these products by the population in Germany.

High intakes of methylmercury result in TWI exceedances for part of the adolescents and young adults aged 14 to under 25 years. The high intake values can be caused by a high consumption of fish and/or seafood as well as by the consumption of species with high concentrations. Detailed analyses have shown that tuna consumers in this age group in particular ingest high levels of methylmercury. However, when it comes to fish, its concentration of contaminants should not be considered in isolation. The health benefits of eating fish should also

be taken into account, including the supply of vitamins, trace elements and certain polyunsaturated fatty acids.

Subject of the assessment

The subject of the present opinion is the assessment of health risks for consumers due to the presence of methylmercury (MeHg) in fish and seafood based on data on concentrations collected in the first German Total Diet Study (TDS) (BfR MEAL Study, Meals for Exposure Assessment and Analysis of Foods (Sarvan et al., 2021)).

Result

Methylmercury (MeHg) is formed from inorganic mercury by the metabolic processes of various anaerobic bacteria in water and accumulates in fish and seafood via the aquatic food chain.

The BfR MEAL study analysed the levels of MeHg in fish species that are among the 90 % most frequently consumed foods in Germany, as well as individual fish species that are consumed less frequently but had particularly high concentrations of certain contaminants such as MeHg in the past. The concentration data was collected on the basis of ready-to-eat food, i.e. the MeHg content of e.g. prepared fish (fried, cooked, smoked, pickled, etc.) was determined. The highest concentrations of MeHg were measured in tuna, dogfish and ocean perch.

In order to investigate the influence of food processing and the different methods of data collection on analytical data for MeHg and total mercury (Hg) in fish and seafood, the analytical data from the BfR MEAL study (ready-to-eat food) were compared with analytical data from monitoring in accordance with Sections 50-52 of the German Food and Feed Code (LFGB) for the years 2012 to 2021 (primarily unprocessed food). Overall, the data from the BfR MEAL study showed good agreement with the mean values of the monitoring data. In the overall view of all species analysed, the influence of the preparation and the methodology of data collection can be assessed as low overall. The differences in the concentrations of total Hg are primarily considered to be species-dependent.

As a result of the exposure assessment for the total population across all age groups, the consumption of pollack contributes the most to the intake of MeHg. Fish with high concentrations of MeHg, such as tuna and ocean perch, are consumed comparatively rarely, but contribute to intake when eaten due to their high content. These fish are consumed less by children and adolescents.

According to EFSA (2012), unborn children are considered to be a population group particularly at risk for the developmental neurotoxic effects of methylmercury exposure. For the health risk assessment of the presence of MeHg in fish and seafood, the BfR uses the tolerable weekly intake (TWI) of 1.3 micrograms (µg)/kilogram (kg) of body weight (bw) and

week derived by EFSA. It is based on observed correlations between exposure to MeHg and impairment of neurological development in children in epidemiological studies.

The following results of the risk characterisation can be summarised:

The mean MeHg exposure for fish and seafood consumers calculated in this opinion is below the TWI of 1.3 µg/kg bw per week (0.19 - 0.47 µg/kg bw per week, upper bound) for all age groups. For consumers of fish and seafood of all age groups in Germany, a low probability of the occurrence of health impairments due to MeHg is therefore assumed for mean exposure.

The high MeHg intake (95th percentile) for consumers of fish and seafood (0.63 - 2.18 µg/kg bw and week, upper bound) is in the range of the TWI or up to 1.7 times higher for some age groups.

For these population groups with a high intake of MeHg, the following results were obtained by analysing different age groups or specific consumption patterns of the fish species consumed:

- The highest intakes were calculated for adolescents aged 14 - <18 years (2.18 µg/kg bw per week) and young adults aged 18 - <25 years (1.53 µg/kg bw per week) based on the consumption data of the NVS II.

- Exceedances of the TWI were also found for certain age groups when looking separately at those consuming tuna (medium and high exposure), but not when looking separately at those consuming pollack or herring. Accordingly, the intake of MeHg can be directly influenced by the choice of fish species consumed.

Exceeding the TWI is to be considered a health concern. For part of the persons with a high exposure (P95) to MeHg through the consumption of fish and seafood, a medium probability of the occurrence of health impairments due to MeHg is assumed according to the present exposure assessment.

Fish and seafood are a source of important nutrients, vitamins and trace elements in human nutrition. When considering measures to reduce the intake of MeHg, the health benefits of consuming fish and the beneficial ingredients it contains should therefore be taken into account in addition to the health risks posed by the presence of this contaminant in fish and seafood.

Rationale

3.1 **Risk assessment**

3.1.1 Hazard identification

Mercury (Hg) is a metal that occurs worldwide in soils, water and air, both in elemental form and bound in salts or organic compounds. It enters the environment through both natural and anthropogenic processes. For example, it is continuously released into the atmosphere through outgassing from the earth's crust, evaporation from water, volcanic eruptions, metal extraction and the burning of coal and is therefore ubiquitously present in the air, albeit in very low concentrations (ATSDR, 2022; EFSA, 2012)

Elemental mercury (Hg^0) is liquid at room temperature and has a significant vapour pressure. Hg^0 is the predominant form of mercury in the atmosphere. It is contained in energy-saving light bulbs, thermometers and barometers and is also an important component of dental fillings containing amalgam (ATSDR, 2022; EFSA, 2012).

Inorganic mercury compounds (iHg; inorganic Hg) are oxides, sulphides or halides of mercury in oxidation state 1 (Hg^+) or 2 (Hg^{2+}). As a natural component of the earth's crust, iHg occurs ubiquitously in small quantities in soils worldwide, is absorbed by plants and thus enters the food chain. In addition, Hg^+ and Hg^{2+} ions are ubiquitously present in the world's oceans and inland waters. IHg is used in various industrial processes and is found, for example, in batteries and fungicides (EFSA, 2012).

Organic mercury compounds such as methylmercury (MeHg) are formed by the metabolic processes of various anaerobic bacteria found in the world's oceans and inland waters. The bacteria primarily convert iHg to MeHg, which accumulates in fish and seafood (mussels, crabs, squid, etc.) via the aquatic food chain. The accumulation depends on the species and the diet, and the degree of accumulation correlates with the size and age of the individuals of the respective species. The highest concentrations are therefore found in large and old predatory fish such as shark, swordfish and tuna (EFSA, 2012).

The general population is exposed to all forms of mercury, but primarily to MeHg through dietary intake (e.g. fish, seafood) and to Hg^0 from dental amalgam. Compared to organic and elemental mercury, the intake of inorganic mercury compounds by the general population is marginal (ATSDR, 2022).

3.1.2 Hazard characterisation

Detailed information on the hazard potential of mercury can be found in the opinions of international bodies (e.g. ATSDR, 2022; EFSA, 2012; JECFA, 2011). Mercury and mercury compounds have no known physiological function in the human body (ATSDR, 2022).

3.1.2.1 Toxicokinetics

Hg^0 is mainly absorbed via the lungs. According to EFSA (2012), amalgam fillings can account for up to 87% of the total mercury ingested by people with a large number of amalgam fillings (EFSA, 2012). Hg^0 is oxidised to iHg in the human body. The absorption rate via the gastrointestinal tract is very low (ATSDR, 2022). Hg^0 does not play a role in exposure to Hg via food, so Hg^0 is not considered further in this opinion.

The absorption rate of iHg in the intestine depends on the solubility of the respective iHg compound and can be up to 16 %. After distribution in the human body, the highest concentrations are found in the kidneys and liver. With regard to the metabolism of iHg, there is limited evidence from studies with mice that a small amount of iHg can be reduced to elemental mercury and exhaled as elemental mercury vapour. Furthermore, it has been detected that bacteria in the saliva and gastrointestinal tract methylate iHg; however, the quantitative significance of methylation remains uncertain. The excretion of iHg occurs mainly via the urine and partly via the faeces, whereby the half-life for excretion from the human body is approx. 49 to 120 days (ATSDR, 2022).

The intake of MeHg occurs through the consumption of fish and seafood. Unlike iHg, MeHg is very well absorbed via the intestine. The absorption rate is stated to be over 80 % to almost 100 % (ATSDR, 2022; EFSA, 2012). In human blood, MeHg accumulates to a large

extent (> 90 %) in the erythrocytes, while in plasma most MeHg (around 99 %) is bound to albumin (EFSA, 2012). Accordingly, MeHg is distributed throughout the body after intake, with the highest concentrations occurring in the liver, kidneys and brain. MeHg has also been found in human umbilical cord blood, placenta and breast milk. MeHg is partially metabolised to iHg in human metabolism, so that after exposure to MeHg, both MeHg and iHg are present in tissues and excreta. The half-life for excretion from the human body for MeHg is about 80 days, with excretion occurring mainly via faeces, urine and hair (ATSDR, 2022).

3.1.2.2 Biomarkers

With regard to biomarkers for exposure to methylmercury, numerous studies have found a positive correlation between fish consumption and total mercury levels in blood, red blood cells and hair. In addition, a significant correlation was found between fish consumption during pregnancy and the total mercury content in the umbilical cord blood (FAO/WHO, 2007). The latter in turn correlates with the total mercury content in the mother's hair (EFSA, 2012; Sakamoto et al., 2012).

Short-term exposure to MeHg in population groups with regular fish consumption is generally well reflected by the total mercury content in whole blood, but iHg may also be present in whole blood. Consequently, depending on the level of iHg exposure, the determination of total mercury in whole blood may lead to an overestimation of MeHg exposure (EFSA, 2012).

While iHg is more evenly distributed between red blood cells and plasma, more than 90 % of MeHg in blood is found in red blood cells. Thus, the determination of the total mercury content in red blood cells is a more accurate biomarker for MeHg exposure compared to the total mercury content in whole blood (ATSDR, 2022; EFSA, 2012).

The total mercury content in hair is the most suitable biomarker for long-term average exposure to methylmercury (EFSA, 2012). The ratio of total mercury in blood to hair is 1:250 (FAO/WHO, 2004; WHO, 1990), although there are large fluctuations, especially in people who rarely eat fish. Similar to mercury in hair, the total mercury content in toenails and fingernails is used to determine the average MeHg exposure and can thus also serve as a biomarker for long-term MeHg exposure (ATSDR, 2022; EFSA, 2012).

However, the total mercury content in urine is not a suitable indicator of exposure to MeHg, as mainly iHg is excreted via urine. Accordingly, there is no strong correlation between the total mercury content in urine and fish consumption (ATSDR, 2022; EFSA, 2012).

3.1.2.3 Toxicity in animal studies

In animal studies, the developing nervous system and the immune system are considered to be the most sensitive target structures after oral exposure to MeHg. Furthermore, adverse effects on the cardiovascular system, kidneys and reproduction have also been reported (ATSDR, 2022; EFSA, 2012).

In a study on developmental neurotoxicity, a daily oral dose of 0.02 milligrams (mg) MeHg/kg bw per day over a period of four weeks before mating, during gestation and lactation and further treatment of the offspring over a period of seven weeks after weaning resulted in smaller litter sizes and lower weight gain of the male offspring in mice. With regard to neurological parameters, altered locomotor activity, impaired locomotor

coordination and impaired auditory function were observed. No NOAEL[1] could be derived in this study, as only a single dose of 0.02 mg MeHg/kg bw per day was tested (Huang et al., 2011).

In a comparable study, reduced locomotor activity was identified as the most sensitive endpoint for rats and a NOAEL of 0.4 mg/kg bw per day was derived for this (Day et al., 2005).

The lowest dose of MeHg for which adverse effects were observed in mice was 0.08 mg/kg bw per day in a developmental immunological study according to EFSA (2012). The most sensitive endpoint identified in this study was a reduced T-cell-dependent antibody response, for which a $BMDL_{05}$[2] of 0.01 mg/kg bw per day (based on MeHgCl) was calculated (Tonk et al., 2010).

ATSDR (Agency for Toxic Substances and Disease Registry 2022) describes an oral dose of 0.0003 mg/kg bw per day as the lowest LOAEL[3] , at which developmental immunological effects occurred in mice (Wild et al., 1997).

However, the results of these animal studies were not used in the EFSA opinion (2012) to derive a health-based guidance value for MeHg; instead, the results of epidemiological studies were used (see 3.1.2.4).

3.1.2.4 Epidemiological studies

As consumer exposure to MeHg correlates strongly with the consumption of fish and seafood, population groups with a high consumption of fish and seafood are well suited for the investigation of possible correlations between exposure to MeHg and any adverse health effects. In various epidemiological studies, the Hg concentrations in the blood or hair of the study participants were quantified rather than using consumption data for the exposure assessment. The concentration of Hg in hair is considered to be the best measure for determining the average long-term exposure to MeHg (EFSA, 2012).

Various epidemiological studies provide evidence of an association between exposure to MeHg and effects on the nervous system, the cardiovascular system and other effects such as the immune and reproductive systems. According to EFSA (2012), the adverse effects on the cardiovascular system associated with exposure to MeHg are inconsistent, but in particular observations related to myocardial infarction, heart rate variability and blood pressure are of potential importance. A number of the effects associated with exposure to MeHg, e.g. on the immune and reproductive systems, are based on single or few studies, some with inadequate study design, and the significance of the results of these studies is difficult to assess (EFSA, 2012).

A large number of epidemiological studies show that the developing nervous system is the most sensitive target of the effects of MeHg. In particular, the results of two mother-child cohorts (Faroe Islands and Seychelles cohorts) showed associations between prenatal

[1] No Observed Adverse Effect Level: highest tested dose at which no adverse health effect is observed
[2] Benchmark Dose Lower Confidence Limit: Dose associated with the lower limit of the confidence interval for the benchmark dose. The benchmark dose is the dose determined by mathematical dose-response modelling that is associated with a certain effect size in the studies underlying this modelling.
[3] Lowest Observed Adverse Effect Level: lowest tested dose at which an adverse health effect is observed

exposure to MeHg and impairment of the developing nervous system (ATSDR, 2022; EFSA, 2012). The results of these two cohort studies are summarised below.

Faroe Islands cohort

On the Faroe Islands, traditionally a lot of fish and seafood is consumed, as well as marine mammals (especially pilot whales). For this reason, the population of the Faroe Islands is particularly suitable for epidemiological studies on the health effects of nutrition with food of marine origin.

In the period 1986 - 2009, five birth cohorts (cohorts of mother-child pairs) were formed in the Faroe Islands, in which, among other things, the level of MeHg exposure was recorded (Grandjean et al., 1997). Associations of MeHg exposure with impairments in neurological development (development of neurological and cognitive abilities) of children aged 2 weeks to 14 years were investigated in the first two of these cohorts, Cohort 1 (n = 1,022, 1986 - 1987) and Cohort 2 (n = 182, 1994 - 1995) (Weihe and Grandjean, 2005). Based on these Faroe Islands cohorts, follow-up studies and a large number of re-analyses were conducted up to the age of 22 years (ATSDR, 2022). The primary measure of prenatal MeHg exposure was total mercury in umbilical cord blood, which contained predominantly (> 80 %) MeHg (Grandjean et al., 1992). In addition, mercury was also measured in maternal hair and infant hair at 1 and 7 years of age and in infant blood at 7 years of age (ATSDR, 2022; EFSA, 2012).

The results on the children's neurological development were assessed using a series of tests based on the age of the children. These included tests of learning and memory, visual-motor function, auditory function, autonomic nervous function, developmental milestones (e.g. sitting, crawling, standing), intellectual performance and behaviour (ATSDR, 2022). As a result, based on the Faroe Islands cohorts and the above-mentioned studies, according to EFSA (2012) and ATSDR (2022), associations were found between concentrations of MeHg in umbilical cord blood and declining performance on tests of cognitive function at 7 years of age (Grandjean et al, 2003; Grandjean et al, 2014; Grandjean et al, 1998; Grandjean et al, 1997), 14 years (Debes et al, 2006; Julvez et al, 2010) and 22 years (Debes et al, 2016). The associations were not consistently observed in all tests of cognitive function. As a basis for selecting the critical dose to derive a health-based guidance value, the negative association between performance on the Boston Naming Test (ability to name object representations) and increasing levels of mercury in umbilical cord blood was identified as the most reliable and sensitive result (Budtz-Jørgensen et al., 1999; NRC, 2000). The association was observed in children aged 7 years in both cohorts 1 and 2. The BMDL05 of 58 µg/kg mercury in cord blood (corresponding to a BMDL05 of 12 mg/kg mercury in maternal hair) was used to derive a health-based guidance value for the developmental neurological limitations of the children in the Faroe Islands cohort at the age of 7 years (EFSA, 2012).

Seychelles cohort

The Seychelles' nutrition is also rich in fish and seafood, but unlike the Faroe Islands, hardly any marine mammals are consumed. In addition, there are hardly any industrial sources of Hg entry in the Seychelles, so that the population's exposure to Hg is essentially due to the consumption of fish and seafood.

Two prospective studies on the relationship between MeHg exposure and neurological development were conducted in the Seychelles: the Seychelles Child Development Study (SCDS) and the Seychelles Child Development Nutrition Study (SCDNS).

The SCDS included a cohort of 779 mother-child pairs (6 months after delivery, 1989 - 1990). Results examining neurological development were initiated at 6 months of age and continued until 24 years of age (Myers et al., 1995; van Wijngaarden et al., 2017). The primary measure of MeHg exposure was average maternal hair mercury levels during pregnancy. The neurological development of the offspring was assessed using a series of age-appropriate tests of motor and cognitive development (learning and memory, visual-motor function, auditory function, developmental milestones, intellectual performance and behaviour). Overall, the prospective SCDS study has not demonstrated consistent associations between exposure to MeHg and neurological development at any age studied to date. This conclusion is supported by further follow-up of the cohort from 6.5 months to 24 years of age and longitudinal analyses (ATSDR, 2022).

In another prospective study (SCDNS), correlations between prenatal exposure to MeHg and motor and cognitive development were investigated (Davidson et al., 2008; Strain et al., 2008). Additional parameters examined in this study were the supply status of the mothers and the intake of certain nutrients in the diet during pregnancy, which have a positive influence on the neurological development of the children. These included arachidonic acid (AA), choline, omega-3 and omega-6 long-chain polyunsaturated fatty acids (LCPUFAs), docosahexaenoic acid (DHA), thyroid hormone status and iron status. This study included 300 pregnant women recruited in 2001, including follow-up of infants and children aged 5 months to 5 years. Neurological development was assessed using learning and memory tests, visual-motor skills and behaviour. This prospective study showed a negative association between maternal MeHg exposure and various developmental neurological endpoints in their children at 9 and 30 months of age when omega-3 LCPUFA levels in maternal blood were included in the statistical evaluation (Davidson et al., 2008). The adverse effect of MeHg on the neurological development of the children outweighed the nutritional benefit in the context of a fish-rich nutrition of the mothers above a MeHg concentration in maternal hair of about 11 mg/kg hair. This value was defined as the NOEL (EFSA, 2012).

Other regions

Other epidemiological studies are available examining the effects on neurological development in further population groups with high dietary exposure to MeHg: New Zealand, Nunavik region of Arctic Canada, Amazon basin, Madeira and Portugal (ATSDR, 2022; EFSA, 2012). In the results on neuronal development, some but not all studies found an association with MeHg concentrations below those reported in the Faroe Islands and Seychelles cohorts. However, according to EFSA 2012, the overall picture at low exposure did not provide sufficient information to draw firm conclusions. In summary, these studies do not provide a better basis for the assessment of the dose-effect relationship than the Faroe Islands and Seychelles studies (EFSA, 2012).

3.1.2.5 Derivation of the health-based guidance values

In an opinion dated 20 December 2012 (updated version dated 10 April 2018), the European Food Safety Authority (EFSA) derived health-based guidance values for MeHg (EFSA, 2012).

A TWI of 1.3 µg/kg bw per week was derived for MeHg (EFSA, 2012). The EFSA has identified impairments in the neurological development of children as the most sensitive endpoint, which can manifest themselves in both motor and cognitive impairments (e.g. fine motor

skills, reaction time, hearing, speech, spatial perception or memory). The TWI derivation for MeHg was based on the results of two epidemiological studies in which a statistically significant association was found in mother-child cohorts between increased MeHg exposure of mothers during pregnancy and poorer results of the children in various motor and cognitive tests at the age of 7 years (Faroe Islands Cohort 1) and 30 months (Seychelles Cohort). The toxicological reference values identified in studies of the Faroe Islands cohort ($BMDL_{05}$ 12 mg Hg/kg maternal hair (Budtz-Jørgensen et al., 1999; EFSA, 2012; NRC, 2000)) and the Seychelles cohort (NOEL 11 mg Hg/kg maternal hair (Davidson et al., 2008; EFSA, 2012)) were used as the starting point for the TWI derivation. The mean of these two values of 11.5 mg Hg/kg maternal hair was used as the starting point for the TWI derivation (EFSA, 2012). As the total mercury content in hair reflects the long-term average methylmercury intake, this starting value of 11.5 mg Hg/kg maternal hair is used to derive the health-based guidance value for MeHg.

According to EFSA (2012), a value of 250 was reported in various biomarker studies for the ratio of the Hg concentration in blood in relation to the Hg concentration in hair (EFSA, 2012; FAO/WHO, 2004; WHO, 1990). Using this conversion factor of 250, a maternal blood Hg concentration of 46 µg/L was calculated. Based on this value, an oral intake of 1.2 µg/kg bw per day was calculated using a toxicokinetic model to convert the equilibrium concentration of Hg in the blood into an average daily intake of Hg (FAO/WHO, 2004). This value therefore indicates the daily intake of Hg, which mathematically leads to a blood serum concentration of 46 µg/L. A TWI for MeHg of 1.3 µg/kg bw per week (expressed as mercury) was derived from this, applying a factor of 2, which takes into account uncertainties in the ratio of Hg concentrations between hair and blood, and a standard factor of 3.2 for inter-individual differences in toxicokinetics and conversion to a weekly intake scenario due to the long half-life (EFSA, 2012).

The ATSDR bases its derivation of a health-based guidance value for MeHg on a meta-analysis of epidemiological data on associations of chronic fish consumption with neurological development (reduction in overall IQ) in the Faroe Islands, New Zealand and the Seychelles population (Axelrad et al., 2007). Based on a No Adverse Effect Level (NAEL) of 0.41 µg/kg and day and a factor of 3 for inter-individual human variability, a slightly lower MRL of 0.1 µg/kg bw and day corresponding to 1.0 µg/kg bw and week (0.41 µg/kg and day x 7 days / adjustment factor of 3) was derived compared to the EFSA TWI (2012) (ATSDR, 2022).

EFSA (2012) does not specifically address the underlying meta-analysis, but concludes that the overall picture of the results at low exposure levels does not provide sufficient information to derive a health-based guidance value (EFSA, 2012).

From the BfR's point of view, the TWI of 1.3 µg/kg bw and week derived by EFSA (2012) represents a suitable basis for a risk characterisation of the alimentary intake of MeHg and is used in the present opinion. The BfR points out that this health-based guidance value reflects the state of scientific knowledge in 2012.

3.1.3 Exposure estimation and exposure assessment

3.1.3.1 Consumption data

The National Nutrition Survey II (NVS II) of the Max Rubner Institute (MRI) served as the data basis for the consumption of adolescents and adults. The NVS II is the current representative

study on the consumption of the population in Germany. The study, in which around 20,000 people between the ages of 14 and 80 were surveyed on their dietary behaviour using three different survey methods (dietary history, 24-hour recall and weighing protocol), took place throughout Germany between 2005 and 2006 (Krems et al., 2006; MRI, 2008). The consumption analyses are based on the data from the two independent 24-hour recalls of the NVS II, which were collected in a computer-assisted interview using "EPIC-SOFT". The data of 13,926 people from whom both interviews were available were evaluated.

The nutrition study as a KiGGS module (EsKiMo II) (Mensink et al., 2021) served as the data basis for the consumption of children and adolescents between the ages of 6 and 11. In the years 2015 to 2017, 2,644 children and adolescents aged 6 to 17 years were examined on their food consumption and dietary behaviour as part of EsKiMo II. They had previously taken part in the second wave of the "Study on the Health of Children and Adolescents in Germany" (KiGGS) wave 2 of the Robert Koch Institute. The food consumption of the 6- to 11-year-old children was determined with the help of their parents using weighing protocols over four days.

The weighing records of the 6- to 11-year-old children were compiled over four days with the help of the parents. Further information on dietary behaviour, such as shared family meals, the availability and use of school meals, special diets and the implementation of weight-reduction diets, was also collected. The 6- to 11-year-old children from whom the weighing records were available (N = 1,190) were taken into account for the exposure assessment.

The "Children's Nutrition Survey to Record Food Consumption" (KiESEL study) served as the data basis for the consumption of infants, toddlers and children aged between 0.5 and 5 years. A total of 1,104 children aged between six months up to and including five years took part in KiESEL. The survey was conducted between 2014 and 2017. Parents and guardians completed a questionnaire on general nutrition, nutrition in the first year of life and a Food Propensity Questionnaire on rarely consumed foods. Of these, 1,008 children or their parents also took part in the nutrition survey using a weighing/estimation protocol. The children's food consumption was documented in a weighing protocol for three consecutive days and in a 1-day weighing protocol on an independent day. In addition, out-of-home consumption (e.g. in the childcare centres) was recorded using a reduced estimation protocol (Nowak et al., 2022a; Nowak et al., 2022b). For the evaluation, the results from the weighing protocols were used and only non-breastfed individuals were considered (N = 952).

The aforementioned consumption studies are suitable for estimating long-term consumption levels.

3.1.3.2 Content of MeHg and total Hg in fish and seafood

Data from the BfR MEAL study, the first German Total Diet Study (TDS), is used to calculate the intake of methylmercury (Sarvan et al., 2017). In a TDS, analytical data is collected in a selection of foods that should cover at least 90 % of the average consumption of the population. Moreover, a TDS analyses ready-to-eat foods, i.e. in the case of fish, for example, the MeHg concentrations in prepared fish (fried, cooked, smoked, pickled, etc.) are determined. The TDS methodology utilises the pool sample approach, i.e. fish of the same species are combined into a pool prior to analysis. In the BfR MEAL study, a pool sample

usually consists of 15 to 20 individual samples. The measured concentration thus represents the mean value of the pooled individual samples.

For certain foods it is of interest in the BfR MEAL study whether regional differences exist in the concentrations of MeHg, for example. In order to analyse regional differences, four regions (North, South, East, West) were defined in Germany. Regional pool samples are made up of 15 individual samples from the respective region (Sarvan et al., 2017).

The BfR MEAL study analysed fish species that are among the 90 % most commonly consumed foods in Germany as well as individual fish species that are consumed in smaller quantities, such as dogfish, which in the past often showed elevated concentrations of contaminants. In addition, various common forms of preparation were also analysed separately for some fish species. For example, the analyses of the foodstuff "herring" were carried out on the basis of various common forms of herring preparation in Germany (herring in sauce; smoked herring; fried herring; ”Matjes”, “Bismarckhering”; “Rollmops”). The selection of fish species and preparation forms was based on consumption studies conducted in Germany (NVS II, VELS).

For the pool samples of the food group "fish and seafood" generated as part of the BfR MEAL study, the concentrations of total Hg and MeHg were determined using two independent analytical methods. MeHg was not calculated using a conversion factor of Hg, as often described in the literature (EFSA 2012), but was measured analytically as MeHg using ICP-MS (Inductively Coupled Plasma Mass Spectrometry). The results are summarised in Table 1.

The methodology and analytical data used here for MeHg (Sarvan et al., 2021) and total mercury (Fechner et al., 2022) are described in the publications mentioned.

Table 1: Concentrations of total Hg and MeHg in pooled samples of fish and seafood from the BfR MEAL study (in mg/kg)

	Total Hg [mg/kg]	MeHg [mg/kg]	Share of MeHg in Total Hg [%]
Fish; national pool samples			
Cod	0.09	0.08	86
Codfish liver	0.02	0.01	68
Spiny dogfish, smoked (e.g. "Schillerlocke")	0.52	0.58	111 *
Eel	0.10	0.10	94
Eel, smoked	0.08	0.08	96
Fish fillet, baked	0.02	0.02	97
Fish fingers	0.01	<0.01	
Halibut	0.08	0.08	104 *
Halibut, smoked	0.11	0.09	86
Herring in sauce	0.04	0.03	77
Herring, smoked	0.08	0.07	97
Herring, fried, pickled	0.05	0.05	95
Herring, pickled ("Matjes", "Bismarck herring")	0.03	0.03	113 *
Herring, pickled („Rollmops")	0.04	0.04	95
Ocean perch	0.12	0.12	96
Plaice, sole	0.06	0.06	103 *
Coalfish, Alaska pollack	0.06	0.07	108 *
Salmon	0.02	0.02	91
Salmon, smoked	0.03	0.02	76
Striped catfish/pangasius	<0.001	<0.01	
Tuna (fillet)	0.37	0.38	102 *
Tuna in its own juice/sauce (canned)	0.13	0.12	94
Tuna in oil (canned)	0.18	0.15	87
Tuna, smoked	0.67	0.70	105 *
Fish; regional pool samples			
Carp (Eastern Region)	0.03	0.03	96
Carp (Northern Region)	0.02	0.02	83
Carp (Southern Region)	0.02	0.01	80
Carp (Western Region)	0.01	<0.01	
Trout (Eastern Region)	0.02	0.02	95
Trout (Northern Region)	0.02	0.02	81
Trout (Southern Region)	0.03	0.03	81
Trout (Western Region)	0.01	0.01	71
Trout, smoked (Eastern region)	0.02	0.01	88
Trout, smoked (Northern region)	0.03	0.03	83
Trout, smoked (Southern region)	0.02	0.02	91
Trout, smoked (Western region)	0.02	0.02	95
Seafood; national pool samples			
Mussels	0.02	0.01	65
Shrimps	0.02	0.02	82
Squid/cuttlefish	0.02	0.02	118 *

* Values >100 % are due to the measurement uncertainties (30 % total Hg and 12 % MeHg) and the measurement in two different laboratories with different methods

The concentrations of both total Hg and MeHg were above the limit of quantification in almost all samples analysed. In the case of total Hg, only the concentration of the pool sample of pangasius was below the limit of quantification (LOQ) of 0.001 mg/kg. For MeHg, the concentrations of the pool samples of fish fingers, pangasius and carp (western region) were below the limit of quantification of 0.01 mg/kg. The highest concentrations of both total Hg and MeHg were measured in tuna, dogfish and ocean perch. In a comparison of the four tuna pools, smoked tuna showed the highest concentrations of total Hg and MeHg, whereas tuna fillet and especially canned tuna showed lower concentrations of total Hg and MeHg (Table 1).

The concentrations of MeHg and total Hg differ significantly in the different fish species (Table 1 and Table 2).

MeHg concentrations in relation to the total Hg concentrations in fish and seafood

According to EFSA, 80-100 % of Hg in fish and seafood is present as MeHg. In a conservative approach, EFSA assumed that 100 % of the mercury in fish is in the form of MeHg (conversion factor of 1.0). For seafood, it was assumed that 80 % of the total Hg is present as MeHg (conversion factor of 0.8) (EFSA, 2012). These conversion factors are necessary in order to be able to make statements about the concentration of MeHg in fish and seafood if only the concentration of total Hg is determined or can be determined.

Both total Hg and MeHg were determined as part of the BfR MEAL study. In most cases, the ratio of MeHg to total Hg in fish was between 80 % and 125 %. The higher MeHg concentrations compared to the total Hg concentrations in pollack, smoked dogfish, marinated herring/matjes/ bismarck herring, squid, tuna fillet, smoked tuna, smoked halibut and plaice/sole can be attributed to the measurement in different laboratories using two different methods. In addition, a measurement uncertainty of 30 % for total Hg and 12 % for MeHg must be taken into account. Only for cod liver (68 %), herring in sauce (77 %), smoked salmon (76 %) and trout (western region: 71 %) was the ratio of MeHg to total Hg below 80 % (Table 1). Therefore, the two data sets confirm the conversion factor of 1.0 proposed by EFSA. For seafood, only one pool sample each for mussels, shrimps and squid was measured in the BfR MEAL study. Here, the ratio of MeHg to total Hg was 65 % for mussels and 82 % for shrimps, which supports the conversion factor of 0.8 proposed by EFSA for molluscs and crustaceans, whereas the value for squid was significantly higher at 118 %.

Regional differences in MeHg concentrations in fish and seafood in Germany

Of the fish analysed as part of the BfR MEAL study, the expert groups accompanying the study considered carp and trout to be the only species for which possible regional differences in the concentrations of MeHg and total Hg in Germany were expected. Therefore, regional pool samples were purchased and analysed for carp, trout and smoked trout. These pool samples show comparatively low concentrations of MeHg and total Hg in the range of 0.01 to 0.03 mg/kg, regardless of the region (Table 1). Overall, the data do not allow any conclusions to be drawn regarding systematic regional differences in MeHg or total Hg concentrations in freshwater fish in Germany.

Influence of the species of preparation on the MeHg concentrations in fish and seafood

The BfR MEAL data indicate whether and to what extent the type of fish preparation has an influence on MeHg and total Hg concentrations. In the case of pollack, processed products

such as fish fingers and baked fish fillet have lower concentrations of MeHg and total Hg than pollack fillet (Table 1). This can presumably be explained by the fact that the proportion of fish fillet and thus the MeHg/total Hg concentration in fish fingers and baked fish fillet is reduced by the high proportion of breading and by the frying fat. In the case of tuna, smoked tuna was found to have about twice the concentration of MeHg or total Hg compared to tuna fillet, whereas canned tuna products had only about half the concentration of MeHg or total Hg (Table 1). In the case of herring, smoked herring also shows higher MeHg and total Hg levels than other herring products such as herring in sauce, fried herring, matjes, Bismarck herring or rollmops (Table 1), although a comparison with herring fillet is not possible here as herring fillet was not analysed as part of the BfR MEAL study. However, smoked fish do not always have higher MeHg or total Hg concentrations. For the species eel, salmon and trout (regional samples), the smoked pool samples did not have higher MeHg or total Hg levels compared to the fillets (Table 1). Overall, it can be concluded that the type of preparation has a measurable influence on the MeHg/total Hg levels in fish, but the data do not allow any general conclusions to be drawn. This would require systematic analyses based on individual samples. Some of the differences discussed here may also be due to the fact that different fish were included in the processed and unprocessed pools of the same species, for example if the fish was purchased already smoked or as a breaded fillet and not prepared in the MEAL kitchen. The overall view of the data clearly shows that the differences in the concentrations of MeHg or total Hg between the different fish species are greater than the differences due to the different types of preparation of the same fish species.

Another important result of the data collection on total Hg and MeHg in the BfR MEAL study is that the different types of fish preparation do not lead to a significant decrease in the concentration of MeHg compared to the total Hg content. The MeHg compounds contained in the fish are apparently very stable and are not converted into other Hg compounds by processing methods such as cooking, frying or smoking. It was not observed for any fish species that the MeHg/total Hg ratio changed significantly due to the type of preparation (Table 1).

Comparison of the analytical data from the BfR MEAL study with analytical data from monitoring

In order to investigate the influence of the different data collection methods on the analytical data for MeHg and total Hg in fish and seafood, the analytical data from the BfR MEAL study (ready-to-eat foods) were compared with analytical data from monitoring in accordance with Sections 50-52 of the German Food and Feed Code (LFGB) for the years 2012 to 2021 (agricultural raw materials or food as available in retail). Table 2 compares the BfR MEAL data with the monitoring data for those species, for which analytical data was collected in the period mentioned. As only total Hg, but not MeHg, was determined as part of the monitoring, the monitoring data must primarily be compared with the total Hg concentrations of the BfR MEAL study. In the case of the BfR MEAL data, only one concentration is available for each pool sample. In the case of the monitoring data, the number of samples, the mean value (MW) of the concentrations as well as the 95th percentile (P95) and the maximum value (Max.) of the measured concentrations of total Hg are listed (Table 2).

Table 2: Analytical data for MeHg and total Hg in fish and seafood from the BfR MEAL study compared to monitoring data for the years 2012 to 2021

Data from the BfR MEAL study			Data from monitoring (2012 - 2021)				
Species	**Total Hg [mg/kg]***	**MeHg [mg/kg]***	**Species**	**Number of samples (N)**	**Total Hg [mg/kg]****		
					MW	P95	Max.
Eel	0.10	0.10	Eel, also smoked (BVL, 2014)	79	0.11	0.25	0.90
Eel, smoked	0.08	0.08					
			Herring (BVL, 2017)	82	0.05	0.08	0.12
Herring in sauce	0.04	0.03					
Herring, smoked	0.08	0.07					
Herring, fried	0.05	0.05					
Herring, pickled, ("Matjes", "Bismarckhering")	0.03	0.03					
Herring, pickled („Rollmops")	0.04	0.04					
Ocean perch	0.12	0.12	Ocean perch (BVL, 2019)	102	0.10	0.19	0.55
Plaice, sole	0.06	0.06	Plaice (BVL, 2013)	143	0.05	0.11	0.19
Coalfish, Alaska pollack	0.06	0.07	Alaska Pollack (BVL, 2015)	121	0.03	0.12	0.18
Salmon	0.02	0.02	Salmon (BVL, 2015)	128	0.02	0.05	0.09
Striped catfish/pangasius	<0.001	<0.010	Slender catfish (Pangasius) (BVL, 2017)	109	0.01	0.01	0.08
Tuna (fillet)	0.37	0.38	Tuna (BVL, 2018)	111	0.20	0.54	0.69
Tuna in its own juice/sauce (canned)	0.13	0.12	Tuna in its own juice (canned) (BVL, 2012)	74	0.14	0.39	0.48
Trout (four regional pools averaged)	0.02	0.02	Trout (BVL, 2014)	108	0.02	0.05	0.14
Carp (four regional pools averaged)	0.02	0.01	Carp (BVL, 2021)	61	0.02	0.05	0.13
Mussels	0.02	0.01	Blue mussel (BVL, 2013)	70	0.02	0.03	0.07
Shrimp	0.02	0.01	Prawns (BVL, 2018)	89	0.01	0.04	0.13
			North Sea crab meat (BVL, 2019)	48	0.07	0.09	0.10

* Mean values of pool samples from 20 individual samples each, exception: trout, here mean value from 4 pool samples with 15 individual samples each

** refers to raw, unprocessed foods, if no further information is given

Overall, the data from the BfR MEAL study show good agreement with the mean values of the monitoring data, even if the samples are not directly comparable due to the partially different composition and preparation. The greatest difference can be seen for North Sea crab meat compared to the pool of shrimps, which cannot be directly compared and for which the mean value of the monitoring data is higher by a factor of 3. For pollack and tuna (fillet), the concentrations of the pool samples of the BfR MEAL study are 1.9 times higher than the mean value of the monitoring data, but, as in all other cases, below the respective P95 of the concentrations from the monitoring.

3.1.3.3 Exposure estimation

The following exposure assessment for the population in Germany is based on the one hand on the data from the National Nutrition Surveys for children, adolescents and adults (KiESEL, EsKiMo II and NVS II) and on the other hand on the data on MeHg concentrations in fish and seafood from the BfR MEAL study, as a wide range of foods was examined here and MeHg was measured directly.

For the exposure assessments, the individual consumption data of the study participants were linked to the MeHg concentrations of the food consumed and related to the individual body weights of the study participants. The analytical data from the regions were linked to the consumption of individuals living in the respective region in order to take into account regional differences in consumption behaviour. Exposure was determined using the lower bound (LB) and upper bound (UB) approach. In the LB approach, all measurements below the LOQ are replaced with 0. In the UB approach, all measurements <LOQ are replaced with the respective LOQ. As the laboratory did not differentiate between the limit of detection (LOD) and LOQ, the LOD was not taken into account when calculating the bounds.

According to the protocols of the consumption studies (KiESEL, EsKiMo II and NVS II), a relevant proportion of the population in Germany did not report any consumption of fish and seafood during the survey period. Exposure assessment is therefore carried out for those who consume fish and/or seafood.

Table 3 shows the number of consumers and the weekly MeHg exposure in the LB and UB scenarios. As the differences between the two scenarios are small, only the UB values are described below.

According to the KiESEL study, 29 % of children aged 0.5 to < 6 years consume fish and/or seafood (279 of 952 participants). With an average consumption of fish and seafood, the MeHg intake of this age group is 0.21 µg per kg bw per week, with high consumption (P95) at 0.76 µg/kg bw per week (Table 3). According to the EsKiMo II study, 29 % of children in the 6-<12 age group consume fish and/or seafood (341 of 1,190 participants). The average exposure to MeHg in this group is 0.24 µg/kg bw per week and 0.93 µg/kg bw per week in the P95. Finally, 2,916 of 13,926 participants (21 %) in the NVS II study (adolescents and adults ≥14 years) stated that they had consumed fish and/or seafood. The mean exposure to MeHg through the consumption of fish and seafood for this group was 0.34 µg/kg bw per week and the high exposure was 1.06 µg/kg bw per week (Table 3).

Taking a detailed look at the age groups, adolescents aged 14 - <18 years show the highest MeHg exposure at 0.47 µg/kg bw and week (UB, average consumption). With a high consumption, the intake of this group reaches a value of 2.18 µg/kg bw and week.

Since, according to EFSA 2012, unborn children are considered to be a population group particularly at risk for the developmental neurotoxic effects of exposure to MeHg, special attention is paid to the group of pregnant and breastfeeding women. Among the fish and seafood consumers in the 24 h recalls of the NVSII, there were only a small number of cases of pregnant and breastfeeding women. These do not allow representative statements to be derived for pregnant and breastfeeding women.

However, statements can be made about the exposure of women of child-bearing age (18 - <45 years) (Table 3). It can be seen that the exposure of this subgroup of the population does not differ from the exposure of the entire adult population in Germany. However, the exposure calculation for women of child-bearing age cannot be directly transferred to pregnant or breastfeeding women, as their consumption behaviour could differ.

In all population groups, pollack has the highest contribution to MeHg exposure (KiESEL: 63 %, EsKiMo II: 54 % and NVS II: 34 %). Pollack is one of the fish species that tends to have low concentrations of MeHg (see Table 1). The high contribution of pollack to MeHg exposure is due to the high consumption. In children (KiESEL), other fish species play a rather subordinate role, as they are hardly ever consumed. The proportion ranges from salmon (8 %) to molluscs (<1 %). In children and adolescents (EsKiMo II), flatfish and tuna contribute 17 % and 13 % to MeHg intake. It should be noted that the contribution of tuna is due to its high concentration (see Table 1), but that it is rarely consumed by this age group (n = 11). All other fish species have a share of ≤ 5 %. In adults (NVS II), tuna (19 %), herring (16 %) and ocean perch (11 %) contribute the most to exposure to MeHg in addition to pollack.

Table 3: Intake of methylmercury for different age groups in the population of Germany (fish and seafood consumers only)

Age group	Number of consumers (N)*	MeHg intake [µg/kg bw and week]			
		MW		P95	
		LB	UB	LB	UB
Infants (0.5 - <1 year)[1]	2 (57)	na	na	na	na
Infants (1 - <3 years)[1]	96 (308)	0.18	0.23	0.81	0.81
Children (3 - <6 years)[1]	180 (588)	0.15	0.19	0.63	0.63
Children (0.5-<6 years)[1]	**279 (952)**	**0.17**	**0.21**	**0.76**	**0.76**
Children (6 - <10 years) [2]	233 (789)	0.23	0.25	0.96	1.09
Adolescents (10 - <12 years) [2]	108 (401)	0.21	0.22	0.81	0.81
Children and adolescents (6-<12 years)[2]	**341 (1,190)**	**0.22**	**0.24**	**0.93**	**0.93**
Adolescents (14 - <18 years) [3]	68 (744)	0.46	0.47	2.18	2.18
Adults (18 - <25 years)[3]	184 (1,393)	0.39	0.40	1.53	1.53
Adults (25 - <35 years)[3]	363 (1,961)	0.33	0.33	1.04	1.04
Adults (35 - <45 years)[3]	561 (2,788)	0.30	0.31	1.00	1.00
Adults (45 - <55 years)[3]	527 (2,443)	0.32	0.32	0.94	0.94
Adults (55 - <65 years)[3]	508 (1,939)	0.35	0.35	1.11	1.11
Elderly (65 - <80 years)[3]	705 (2,657)	0.34	0.34	1.03	1.03
Adolescents and adults (≥14 years)[3]	**2.916 (13,926)**	**0.34**	**0.34**	**1.06**	**1.06**
Women of childbearing age (18 - <45 years)[3]	521 (3,018)	0.32	0.33	1.02	1.02

*Number of all respondents in the respective age group in brackets; na: not analysable due to the insufficient number of consumers (n < 20) in the corresponding age group; consumption studies [1]: KiESEL; [2]: EsKiMo II; [3]: NVS

The exposure assessment shown in Table 3 was carried out on the basis of the analytical data in the LB and UB. The resulting intake values differ only slightly from each other for average consumption of fish and seafood and are also comparable for high consumption (P95) (Table 3). For this reason, only the UB values are given below; the LB values are not given.

In order to investigate the influence of the fish species consumed on consumers' exposure to MeHg in more detail, the exposure of consumers of pollack, herring and tuna was calculated as an example (Table 4). All forms of preparation of the respective fish species were taken into account, i.e. the group of pollock consumers includes, for example, those who have eaten pollock fillet, fish fingers and/or baked fish fillet (see Table 1). The MeHg intake via the respective fish species and the intake via other fish species was calculated for the respective group of people.

Based on the data of the NVS II consumption study, 14 - <18-year-olds who consume tuna already have a total MeHg intake of 2.23 µg/kg bw per week at medium consumption levels; at high consumption levels, their total intake is 4.64 µg/kg bw per week. Based on the NVS II data, a high intake (P95) of tuna leads to high MeHg intakes in almost all age groups of the NVS II (Table 4). Regarding MeHg intake in children and adolescents (KiESEL and EsKiMo II), a statement can only be made about those consuming pollack, as the number of people consuming herring and tuna (between 0 and 7 consumers) is too small to be able to make

valid statements. The MeHg exposure of pollack consumers is in the range of the exposure of fish and seafood consumers as a whole (see Table 3 and Table 4).

This analysis of exposure in relation to selected fish species shows that the frequent consumption of species that can have high concentrations of MeHg (such as tuna) can lead to high exposure. In contrast, frequent consumption of fish species that have comparatively low MeHg concentrations (such as pollack or herring) does not result in increased exposure with the quantities consumed by the population in Germany.

Table 4: Methylmercury intake of different age groups of the population in Germany through the consumption of fish and seafood (only consumers of fish and seafood), as well as in separate consideration of consumers of tuna, herring or pollack (UB)

Age group	MeHg intake (UB) [µg/kg bw and week]								
	Consumers of pollack			Consumers of herring			Consumers of tuna		
	N	MW	P95	N	MW	P95	N	MW	P95
0.5 - <1 year[1]	2	na	na	0	na	na	0	na	na
1 - <3 years[1]	72	0.23	0.79	0	na	na	0	na	na
3 - <6 years[1]	127	0.21	0.68	7	na	na	0	na	na
6 - <10 years[2]	171	0.24	1.01	4	na	na	5	na	na
10 - <12 years[2]	72	0.23	0.90	4	na	na	7	na	na
14 - <18 years[3]	68	0.36	1.18	6	0.22	0.52	6	2.23	4.64
18 - <25 years[3]	184	0.31	1.06	26	0.24	0.50	27	1.10	3.49
25 - <35 years[3]	363	0.31	0.78	54	0.19	0.41	62	0.70	1.30
35 - <45 years[3]	561	0.34	0.94	113	0.23	0.48	51	0.69	3.13
45 - <55 years[3]	527	0.42	0.91	132	0.24	0.63	49	0.53	1.07
55 - <65 years[3]	508	0.41	1.04	131	0.23	0.77	32	0.70	2.17
65 - <80 years[3]	705	0.42	0.85	240	0.20	0.54	21	0.58	2.83

N: number of consumers; na: not analysable, due to the insufficient number of consumers (N < 20) in the corresponding age group; consumption studies [1]: KiESEL; [2]: EsKiMo II; [3]: NVS II

MeHg intake in Germany in a European comparison

In the following section, the exposure assessments for Germany are presented in a European comparison. The exposure assessment for MeHg presented here is compared on the one hand with the EFSA exposure assessment from 2012 and on the other hand with the exposure assessments of other European TDS.

When comparing with the EFSA exposure assessment (2012), it should be noted that EFSA combined data from national nutrition surveys of the Member States with analytical data for total Hg collected in the European Union in the period from 2002 to 2011 for its exposure assessment (EFSA, 2012). For fish and seafood, the measured concentrations of total Hg were converted to MeHg levels according to the conversion factors of 1.0 for fish and 0.8 for molluscs and crustaceans.

Data from the French TDS for adults (Arnich et al., 2012) and for children (Sirot et al., 2018) as well as a Spanish TDS (Valencia region (Marin et al., 2017)) were used to compare the present exposure assessment with the exposure estimates for MeHg from other European TDS. In the exposure estimates of these TDS, as in the present exposure assessment, only the exposure of fish and seafood consumers to MeHg was considered. In one study (Marin et al., 2017), MeHg was determined directly in parallel with total Hg, whereas in the other

two studies (Arnich et al., 2012; Sirot et al., 2018) only total Hg was measured and it was assumed that total Hg corresponds to 100 % methylmercury. The results of the various exposure assessments for adults and children are shown in Table 5 and Table 6 respectively. It should be noted that the age ranges selected for the different exposure assessments are not always identical.

Table 5: High exposure to methylmercury from fish or fish and seafood consumption for adults in a European comparison (fish or fish and seafood consumers only)

Country	Exposure [µg/kg bw and week]	Age range	References
France	P95: 0.43[b,e]	18 - 79 years	(Arnich et al., 2012) (there Table 4)
Spain	P99: 12.7 - 13.0[b,d]	>15 years	(Marin et al., 2017)
Europe	P95: 0.58 - 6.17 (UB)[a,c,e]	18 - <65 years	(EFSA, 2012) (there Table 15)
Germany	P95: 2.07 (UB)[a,e]	18 - <65 years	(EFSA, 2012) (there Table D8)
Germany	P95: 1.06 (UB)[b]	≥14 years	this opinion

[a] only consumers of fish
[b] only consumers of fish and seafood
[c] indicates the range of exposure at the 95th percentile calculated by EFSA on the basis of the various consumption studies of the Member States (minimum - maximum)
[d] optimistic and pessimistic scenario. In the optimistic scenario, measured values < LOQ were set = 0 and only foods for which at least 20 % of the measured values were > LOQ were included in the exposure assessment. In the pessimistic scenario, measured values < LOQ were set = LOQ and all foods were included in the exposure assessment.
[e] calculated from the exposure to mercury under the assumption that the proportion of methyl mercury is 100 %.

Table 6: High exposure to methylmercury from fish and seafood consumption for children in a European comparison (fish and seafood consumers only)

Country	Exposure [µg/kg bw and week]	Age range	References
France	P95: 0,68[b,e]	3 - 17 years	(Arnich et al., 2012)
Spain	P99: 23,8 - 23,9[b,d]	6 - 15 years	(Marin et al., 2017)
Europe	P95: 1.43 - 7.49 (UB)[a,c,e]	3 - <10 years	(EFSA, 2012) (there Table 15)
Europe	P95: 0.81 - 7.29 (UB)[a,c,e]	10 - <18 years	(EFSA, 2012) (there Table 15)
Germany	P95: 3.05 (UB)[a,e]	14 - <18 years	(EFSA, 2012) (there Table D8)
Germany	P95: 0.63 (UB)[b]	3 - <6 years	this opinion
Germany	P95: 0.93 (UB)[b]	6 - <12 years	this opinion

[a] only consumers of fish
[b] only consumers of fish and seafood
[c] is the range at the 95th percentile calculated by EFSA on the basis of the various consumption studies carried out by the Member States
[d] optimistic and pessimistic scenario. In the optimistic scenario, measured values < LOQ = 0 and only foods for which at least 20 % of the measured values were > LOQ were included in the Exposure assessment. In the pessimistic scenario, measured values < LOQ = LOQ and all foods were included in the Exposure assessment.
[e] calculated from the exposure to mercury under the assumption that the proportion of methyl mercury is 100 %.

As the consumption patterns and also the quantities of fish and seafood consumed vary greatly in the Member States of the European Union, the level of exposure of the population in the Member States can also vary significantly.

At European level, the high exposure (P95) of fish consumers to MeHg ranges from 0.58 to 6.17 µg/kg bw/week in the adult population of the EU Member States (Table 5) and from 0.81 to 7.49 µg/kg bw/week in children (Table 6) (EFSA, 2012).

Data on the exposure of the German population to MeHg can be found in Appendix D (Exposure) of the EFSA opinion. According to this, the exposure in the P95 of fish eaters to MeHg (UB) in adults in Germany is 2.07 µg/kg bw per week. For adolescents between 14 and 18 years of age, the exposure to MeHg (P95 of consumption, UB) in Germany is 3.05 µg/kg bw per week ((EFSA, 2012); Table 6). The exposure calculated by the EFSA for Germany (EFSA 2012) and the exposure assessment presented here are in the middle range of the exposure estimated by the EFSA for all Member States for both children and adults in a Europe-wide comparison (EFSA 2012, Table 5 and Table 6).

Compared to the results of the other European TDS, the high exposure to MeHg in adults in Germany determined in the context of this opinion, at 1.06 µg/kg bw and week (UB) from the consumption of fish and seafood, lies between the calculated exposure in France and Spain (Table 5). In children, the exposure to MeHg in Germany is 0.63 µg/kg bw per week (3 - <6 years) and 0.93 µg/kg bw per week (6 - <12 years), which is in the range of the intake in France and significantly lower than the P99 in Spain (Table 6). The differences in exposure can primarily be explained by the consumption of different fish species in the different countries. For example, the consumption of swordfish, which can contain high concentrations of MeHg, contributes to 43 % of the exposure to MeHg in adults and 59 % in children in the Spanish TDS (Marin et al., 2017). However, swordfish is hardly consumed in Germany, is therefore not included in the food list of the BfR MEAL study and therefore does not contribute to exposure in Germany in the exposure assessment presented here. It should be noted that exposure to MeHg can be influenced in particular by the choice of fish species consumed.

3.1.4 Risk characterisation

For the risk characterisation of MeHg in fish and seafood, the BfR uses the TWI of 1.3 µg/kg bw and week derived by the EFSA. The TWI is based on observed associations between exposure to MeHg and impairment of neurological development in children in epidemiological studies. According to EFSA (2012), unborn children are considered to be a population group particularly at risk for the developmental neurotoxic effects of methylmercury exposure.

Looking at the population as a whole, the consumption of pollack, tuna, herring and ocean perch contributes the most to exposure to MeHg in adolescents and adults and the consumption of pollack, ocean perch, plaice and herring in children.

The mean intake of MeHg for consumers of fish and seafood for all age groups is in the range of 0.19 - 0.47 µg/kg bw per week (UB). Accordingly, the mean exposure to MeHg calculated in this opinion is below the TWI of 1.3 µg/kg bw per week for all age groups, including women of child-bearing age (see Table 7). For consumers of fish and seafood of all age groups in Germany, a low probability of the occurrence of health impairments due to MeHg is therefore assumed at mean exposure.

The high MeHg intake (P95) for consumers of fish and seafood is in the range of 0.63 - 2.18 µg/kg bw and week (UB).

For the population groups with high MeHg intake, consideration of differentiated population groups or specific consumption patterns of the fish species consumed yields the following results:

- The highest intakes were calculated for adolescents aged 14 - <18 years (P95: 2.18 µg/kg bw per week) and young adults aged 18 - <25 years (P95: 1.53 µg/kg bw per week) based on the NVS II consumption data. In these age groups, the high exposure exceeds the TWI by a factor of 1.2 to 1.7 (Table 7).
- Exceedances of the TWI were also found for certain age groups when looking separately at those consuming tuna (mean and high exposure), but not when looking separately at those consuming pollack or herring (Table 7). Accordingly, the intake of MeHg can be directly influenced by the choice of fish species consumed.

Exceeding the TWI is to be considered a health concern. For some of the persons with a high exposure (P95) to MeHg through the consumption of fish and seafood, a medium probability of the occurrence of health impairments due to MeHg is assumed according to the present exposure assessment.

Table 7: Intake as a percentage of the TWI of 1.3 µg/kg bw and week for different age groups of the population of Germany through the consumption of fish and seafood or when considering separately those consuming tuna, herring or pollack (UB, only consumers of fish and seafood). TWI exceedances are emphasised in bold.

Age group	**Intake [% TWI]**							
	Consumers of fish and seafood		**Consumers of pollack**		**Consumers of herring**		**Consumers of tuna**	
	MW	**P95**	**MW**	**P95**	**MW**	**P95**	**MW**	**P95**
0.5 - <1 year[1]	na	na	na	na	na	na	na	na
1 - <3 years[1]	18	62	18	61	na	na	na	na
3 - <6 years[1]	15	48	16	52	na	na	na	na
6 - <10 years[2]	19	84	18	78	na	na	na	na
10 - <12 years[2]	17	62	18	69	na	na	na	na
14 - <18 years [3]	36	**167**	28	91	17	40	**172**	**357**
18 - <25 years[3]	31	**118**	24	82	18	38	85	**268**
25 - <35 years[3]	25	80	24	60	15	32	54	**100**
35 - <45 years[3]	24	77	26	72	18	37	53	**241**
45 - <55 years[3]	25	72	32	70	18	48	41	82
55 - <65 years[3]	27	85	32	80	18	59	54	**167**
65 - <80 years[3]	26	79	32	65	15	42	45	**218**

na: cannot be analysed due to the insufficient number of consumers in the relevant age group
Consumption studies: [1] KIESEL; [2] EsKiMo II; [3] NVS II

3.1.5 Discussion and uncertainties

The concept of a TDS includes the creation of a food list consisting of foods that are representative of the consumption behaviour of at least 90 % of the population. This means a reduction in uncertainty regarding the analytical data of a TDS compared to other data collections, such as monitoring in accordance with Sections 50-52 LFGB. From a methodological point of view, it is also advantageous that content determinations in a TDS are carried out on the basis of prepared and ready-to-eat food and thus changes in concentrations that may occur during the preparation of meals are taken into account. Another methodological aspect of data collection as part of a TDS is that the content determinations are carried out using pool samples and therefore no statements can be made about a statistical distribution of the measured concentrations over a larger number of individual samples. This means that the analytical data collected in the course of a TDS

are not suitable for monitoring maximum levels. However, they do provide a representative data set with regard to the average concentrations of a wide range of foods and thus offer a very good basis for determining long-term exposure (Kolbaum et al., 2022). As part of the BfR MEAL study, the intake of MeHg was determined exclusively on the basis of products in the main food group "fish and seafood". Other foods potentially containing fish (e.g. composite foods such as pizza with seafood) were not taken into account, which may lead to a slight underestimation.

For an exposure assessment, analytical data must be combined with consumption data. The data for children and adolescents (KiESEL, EsKiMo II) were collected as part of KiGGS wave 2 between 2014 and 2017. The consumption data for adults (NVS II) were collected in 2005/2006. It cannot be ruled out that the consumption habits of the population in Germany have changed since then, including with regard to the consumption of fish and seafood. Changes in consumption habits can affect both the quantities consumed and the species of fish consumed. These changes can result in both an underestimation and an overestimation of exposure.

Possible changes in the consumption behaviour of the adult population in Germany were investigated as part of the NEMONIT study by the Max Rubner Institute. To this end, some of the participants in the NVS II study were examined to determine whether their consumption behaviour changed between 2006 and 2012. With regard to the consumption of fish and seafood, no changes in consumption behaviour were found (Gose et al., 2016). In the NVS II, consumption data was only collected as part of two 24-hour protocols. In the case of infrequently consumed foods, it is therefore probable that the proportion of consumers is underrepresented. For example, according to the NVS II, the proportion of consumers of fresh tuna is 0.3 % and that of canned tuna is 2.5 %. However, a representative telephone survey in Germany came to the result that 68.7 % of respondents occasionally consume fresh tuna and 30.1 % occasionally consume canned tuna (Ehlscheid et al., 2014). The underrepresentation of rarely consumed fish and seafood in the NVS II probably leads to an underestimation of exposure to MeHg in the group of adolescents and adults in Germany. The same effect cannot be ruled out for children and adolescents from the KiESEL and EsKiMo II studies. However, due to the logging of consumption over four days, this effect is lower.

Consumer exposure to MeHg occurs almost exclusively through the consumption of fish and seafood. Analogue to EFSA's approach, an exposure assessment was therefore carried out on the basis of fish and seafood. It should be noted that low concentrations of MeHg have also been reported for a few other foods, such as mushrooms (Rieder et al., 2011) and rice (Rothenberg et al., 2014), and exposure may therefore be underestimated. A possible intake of MeHg with breast milk was not considered.

3.2 Other aspects

This opinion focuses exclusively on the risks associated with dietary exposure to MeHg and does not assess the health benefits of e.g. fish and seafood. Fish and seafood are a source of important nutrients, vitamins and trace elements, such as proteins, long-chain omega-3 fatty acids (eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA), vitamin D, iodine, selenium and vitamin B12 (VKM, 2022).

In 2010, the FAO and the WHO convened a joint expert committee to assess the risks and benefits of fish consumption. The task of the expert consultation was to review data on the concentration of nutrients (omega-3 fatty acids) and certain contaminants (MeHg and dioxins) in a number of fish species and to compare the health benefits of fish consumption and nutrient intake with the health risks associated with the contaminants contained in fish. The committee concluded that, weighing the benefits of DHA against the risks of MeHg, the consumption of fish by women of child-bearing age, pregnant women and breastfeeding mothers overall reduced the risk of suboptimal neurological development in their offspring compared with not eating fish in most of the cases studied. For infants, toddlers and adolescents, the evidence was not sufficient to derive a quantitative framework for health risks and benefits (FAO/WHO, 2011).

According to EFSA 2015, for infants, children and women of child-bearing age, the benefits of fish consumption should be achieved by increasing the consumption of low-mercury fish species. To protect the foetus from harmful effects of MeHg on neurological development, women of child-bearing age in particular should not exceed the TWI. Apart from limiting the consumption of fish/seafood with high Hg concentrations in the daily nutrition to avoid regular exposure above the TWI, EFSA points out that it is not possible to give general recommendations for fish consumption across Europe. Each country should therefore consider its fish consumption and carefully assess the risk of exceeding the TWI for MeHg while taking into account the health benefits of eating fish/seafood (EFSA, 2015).

A comprehensive and up-to-date benefit and risk assessment of fish consumption was carried out by the Norwegian Scientific Committee for Food and Environment (VKM) in 2022. This consists of a quantitative analysis of the benefits and risks of fish consumption as well as a semi-quantitative benefit assessment of the nutrients in fish and a semi-quantitative risk assessment of the contaminants in fish. The nutrients considered included long-chain omega-3 fatty acids, vitamin D, iodine, selenium and vitamin B12, and in addition to MeHg, other contaminants were included in the analysis (dioxins, dioxin-like polychlorinated biphenyls (PCBs) and per- and polyfluorinated alkyl substances (PFAS)). The results of the analysis indicate that an increase in fish consumption could reduce the number of cases of stroke, coronary heart disease and cognitive disorders (e.g. Alzheimer's disease and dementia) among adults in Norway. In addition, the recommended intake of fish would also improve selenium and iodine intake. With regard to vitamin D intake, it is concluded that low vitamin D intake cannot necessarily be corrected by higher fish intake alone, but that higher fish intake, and in particular oily fish intake, could be important for population groups with low vitamin D levels. In summary, according to VKM, all age groups in Norway would benefit from increasing fish intake to the recommended consumption quantities of fish. On the other hand, it was pointed out that an increase in fish consumption to the recommended consumption quantities would result in the exposure of almost all age groups exceeding the health-based guidance values for the contaminants studied (VKM, 2022).

In summary, it should be emphasised that when considering measures to reduce the intake of MeHg, the health benefits of consuming fish and the nutrients and trace elements it contains should be taken into account in addition to the health risks posed by the presence of these contaminants in fish and seafood.

Further information on the BfR website on methylmercury in fish and seafood

Fish consumption during pregnancy and breastfeeding: Some fish species have high levels of methylmercury
https://www.bfr.bund.de/cm/349/fish-consumption-during-pregnancy-and-breastfeeding-some-fish-species-have-high-levels-of-methylmercury.pdf

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Publisher:
German Federal Institute for Risk Assessment
Max-Dohrn-Straße 8-10
10589 Berlin, Germany
T +49 30 18412-0
F +49 30 18412-99099
bfr@bfr.bund.de
bfr.bund.de/en

Institution under public law
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