Risks of health effects to humans in the UK from ammunition-derived lead

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ABSTRACT

Lead is a toxic metal to which humans in the UK were formerly exposed through a wide range of pathways such as occupational exposure, lead plumbing, paints, petrol additives and foods. Controls on most of these sources have left dietary lead as the main pathway of lead exposure in the UK. This paper shows that ammunition-derived lead, especially from gamebird meat, is the predominant and significant cause of exposure to dietary lead in the small proportion of the UK population who eat gamebird meat frequently. Using information from surveys of gamebird meat consumption by the general population and of high-level game consumers who eat game at least once per week, we estimate minimum and maximum numbers of people who eat game and numbers of these potentially at risk of a set of adverse health outcomes. In the UK, at least one million people eat gamebird meat at least once per year and at least tens of thousands of people from the shooting community are high-level consumers of wild-shot game. Children are likely to be the most numerous group vulnerable to significant negative effects. We estimate that thousands of children in the UK per year (probably in the range 4,000 - 48,000) could be at potential risk of incurring a one point reduction in IQ or more as a result of current levels of exposure to ammunition-derived dietary lead. Numbers of adults at potential risk of incurring critical health effects appear to be smaller.

Key words: *human health, lead, game meat, gamebird meat, high-level consumer, diet survey, children, blood lead, IQ*

INTRODUCTION

Lead is a toxic metal that has a wide range of effects on the health and functioning of humans. There is no known biochemical requirement for lead in humans and other animals. Information on the adverse effects of lead on human health has accumulated over time and indicates that there are effects on most body systems, some of which are detectable at low levels of blood lead (EFSA 2010). In this paper, we first assess the degree to which humans in the UK are exposed to dietary lead derived from spent ammunition. We then consider the potential magnitude of effects of exposure to ammunition-derived lead on health and functioning. Finally, we make approximate estimates of the numbers of people in the UK who may be at risk of negative health effects from the ingestion of ammunition-derived lead.

Routes by which lead is absorbed by humans and its fate in the body

Inorganic lead can, to some extent, be absorbed through the skin, but primarily enters the bloodstream following ingestion of contaminated dust, paint fragments, food and water or inhalation of dust. The primary route of exposure to lead in Europe is in the diet (EFSA 2010). The amount and rate of absorption of ingested lead depends on the individual (age, nutritional status *etc.*) and the physical and chemical characteristics of the material ingested. Children absorb proportionately more ingested lead than adults. Once absorbed, lead is transported around the body in the bloodstream. It is excreted primarily in faeces and urine, but is also incorporated into hair and lost when hair is shed. Lead is also transferred from the blood to soft tissues such as the liver and kidneys and to bone where it accumulates. The half-life of lead in blood is about 30 days, but in bone it is several decades, although a labile compartment exists (USASTDR 2007). Hence, lead is accumulated in the body over the lifetime of an individual, primarily in bone, and lost only slowly. About 94% of the total lead body burden in adults is in the bone, compared with about 73% in children. Lead may be mobilised from bone in times of physiological stress, resulting in elevated blood lead concentrations (USATSDR 2007).

Quantity of gamebird meat consumed annually and minimum number of consumers in the UK

We used data from the UK National Diet and Nutrition Survey (NDNS) programme to estimate the mean quantity of gamebird meat eaten per year by people in the UK (NatCen Social Research 2014). NDNS provides detailed quantitative information on food intake and diet composition based on surveys of a representative sample of UK citizens. We used data from the core survey based on 4-day diet diary results collected in the four survey years 2008/09-2011/12 (NatCen Social Research 2014). We used data from the 4,071 subjects for whom the diet was reported on all four diary survey days. For each subject, we extracted the variable GameBirdsg, which is the mean quantity in grams of gamebird meat consumed per day. This is the only measure of game meat consumption included in the NDNS. This variable was non-zero for 87 subjects. We coded the age of each subject as the midpoint of the age class. For example, the midpoint of the age class coded as 15 years was 15.5. The exception to this was the age class 1 year. The survey only covers children older than 1.5 years, so this class midpoint was coded as 1.75 years.

To relate the proportion of subjects for which consumption of gamebird meat was reported in the 4-day diary period to subject age and sex, we fitted three asymptotic non-linear models:

$\mathbf{P_g = exp(A)}$	**Model 1,**
$\mathbf{P_g = exp(A – B\ exp(-C\ Age))}$	**Model 2,**
$\mathbf{P_g = exp(A_s – B\ exp(-C\ Age))}$	**Model 3,**

where $\mathbf{P_g}$ is the proportion of subjects for whom gamebird consumption is reported, **A** is a constant representing the logarithm of the asymptotic proportion of subjects who eat gamebird meat, **B** and **C** are constants and **Age** is the age class midpoint in years. The parameter **A** was assumed not to differ between males and females in Model 2, but to take different values for the two sexes in Model 3. We calculated the binomial probability of observing the recorded numbers of subjects of each age and sex who did and did not consume gamebird meat under each of the three models. For each model, we used a quasi-Newton algorithm to obtain the parameter values at which the log-likelihood of the data was maximised. We used bootstrap resampling, with replacement, of the 4,071 subjects to obtain confidence intervals of parameter estimates and derived values. We performed 1,000 bootstrap replicates and took the bounds defined by the central 950 bootstrap estimates to represent the 95% confidence limits.

Model 2, which assumes that the proportion of people who consumed gamebird meat changed with age, but did not differ by sex, had the lowest value of the Akaike Information Criterion (AIC) (Model 1 AIC = 843.29, Model 2 AIC = 832.64, Model 3 AIC = 833.95). Likelihood-ratio tests indicated a highly statistically significant effect of age on the proportion consuming gamebird meat (Model 2 vs Model 1, $\chi^2_{(2)} = 14.65$, $P = 0.0007$), but no indication of a significant effect of sex (Model 3 vs Mode l 2, $\chi^2_{(1)} = 0.69$, $P = 0.405$). We therefore selected Model 2 as providing an adequate description of the data. The proportion of subjects consuming gamebird meat increased most rapidly with advancing age over about the first 20 years, being less than 1% for the youngest infants and about 3% for adults (see Figure 1).

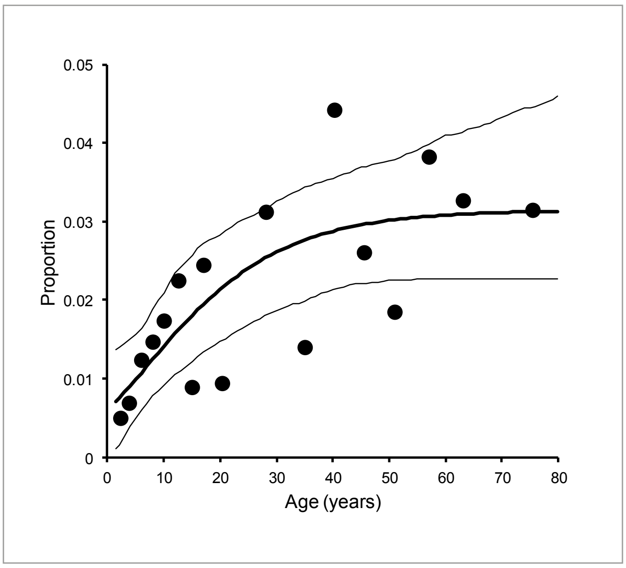

Figure 1: **Proportion of individuals who consumed gamebird meat during a 4-day diet diary survey conducted as part of the UK National Diet and Nutrition Survey in the years 2008/09 - 2011/12 in relation to age.** *Each symbol represents the proportion for a group of individuals in an age class that included at least 200 subjects. The thick curve shows the asymptotic relationship* $P_g =$ *exp(-3.459-1.668 exp(-0.073 Age)) fitted to the disaggregated data by a maximum-likelihood method. The thin curves show bootstrap 95% confidence limits. Results are shown for both sexes combined because there was no indication of a significant difference between the sexes.*

We next multiplied the number of people estimated to be in each year class of age in the UK (in mid-2013, from Office of National Statistics 2014) by the estimated proportion of people consuming gamebird meat for that age class from the analysis reported above. Uncertainty in these estimates of proportions was taken into account by the bootstrap method, but UK population totals were taken to have been estimated without error. The total number of people estimated to consume gamebird meat in a typical 4-day period was 1,613,341 (95% C.L. 1,293,414 – 1,931,975), which represents 2.52% of the UK population (95% C.L. 2.02 – 3.01). Equivalent estimates were made for sub-groups based on age. The estimated number of children up to the age of 8.0 years that ate gamebird meat is 49,576 (95% C.L. 29,083 – 87,870). The estimated number of children between 8.0 and 18.0 years that ate gamebird meat is 119,780 (95% C.L. 77,530 – 178,574). The estimated number of adults that ate gamebird meat is 1,443,984 (95% C.L. 1,091,320 – 1,741,397). It should be noted that these are estimates of numbers of people eating gamebird meat in a typical four day period. They are likely to be representative of the situation for any time of year because proportions of people eating gamebird meat have previously been found to be similar within and outside the shooting season (Taylor *et al.* 2014). However, the numbers of people eating gamebird meat over a longer period, such as a year, would be larger than this unless people are completely consistent from one 4-day period to another in whether they eat game or not. Hence, these estimates are minimum numbers of consumers of gamebird meat.

We analysed the NDNS data on the mean quantity of gamebird meat eaten per day using polynomial ordinary least squares regression of log-transformed values. This analysis included data only from the 87 subjects who consumed gamebird meat. We fitted the first-, second-, third-, fourth- and fifth order polynomial regressions on the age class midpoint in years. In none of these regression models did the effect of age on daily gamebird meat consumption rate approach statistical significance (P always > 0.50). Similarly, the effect of sex did not approach statistical significance in any model (P always ≈ 0.50). Visual inspection of the data (Figure 2) similarly confirmed no sign of consistent effects of age or sex. We therefore used a single log-normal distribution with no effects of age or sex to describe the distribution of values. We used bootstrap resampling of the 87 subjects, with replacement, to obtain confidence intervals of parameter estimates. We performed 1,000 bootstrap replicates and took the bounds defined by the central 950 bootstrap estimates to represent the 95% confidence limits. The mean of the $\log_e$-transformed daily consumption rate in g/d was 2.511 (95% C.L. 2.294 - 2.725), which is equivalent to a geometric mean of 12.3 g/d (95% C.L. 9.9 – 15.3). The standard deviation of the log-normal distribution was 1.044 (95% C.L. 0.896 – 1.160). The arithmetic mean daily consumption rate was 19.1 g/d (95% C.L. 15.5 – 22.6). Although these data derive from 4-day diet diary periods, the arithmetic mean daily consumption rates for those who eat gamebird meat are likely to apply to the whole year, because sampling was representative of the whole year.

We estimated the total mass of gamebird meat eaten per year by the whole UK population by multiplying the estimated numbers of consumers by the arithmetic mean amount eaten per day and the number of days in a year, with uncertainty in numbers of people and consumption rates accounted for using the bootstrap method. The total mass of gamebird meat eaten per year by the whole UK population was estimated to be 11,232 tonnes (95% C.L. 9,162 – 16,251).

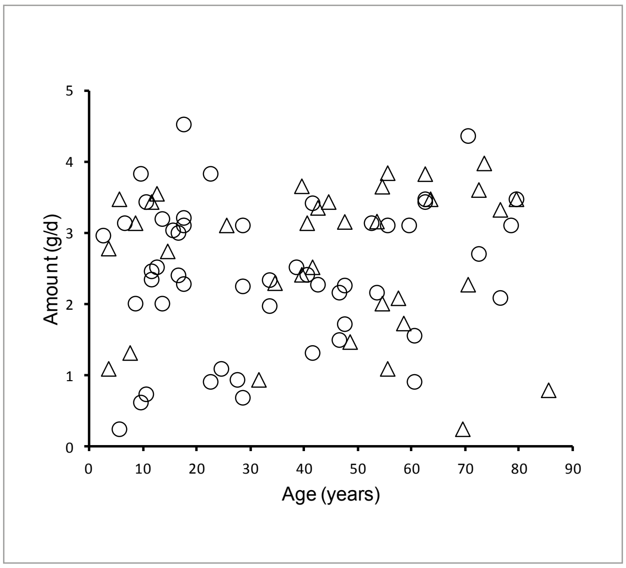

Figure 2: **Mean amount (g) of gamebird meat eaten per individual per day averaged over a 4-day diet diary survey period for those individuals who ate some gamebird meat during the diary period.** *Data are from surveys conducted as part of the UK National Diet and Nutrition Survey in the years 2008/09 -2011/12. Amounts eaten per day are* log_e *-transformed and shown in relation to age. Each symbol represents the datum from one individual. Results for males are shown by triangles and those for females by circles.*

An independent check on the quantity of gamebird meat consumed annually in the UK

Numbers of wild gamebirds and waterfowl shot in the UK in 2004 are given in PACEC (2006) as just under 19 million, of which about 79% were pheasants *Phasianus colchicus*. This total excludes woodpigeons *Columba palumbus*, which PACEC (2006) treats as pests, rather than game. Results from game bag records collected by the Game and Wildlife Conservation Trust and presented by Aebischer (2013), show that numbers of pheasant, red-legged partridge *Alectoris rufa*, grey partridge *Perdix perdix* and mallard *Anas platyrhynchos* shot in 2011 were 12 – 23% higher than they were in 2004, with the scale of increase varying among the four species. Because of the preponderance of pheasants in the national bag of gamebirds and waterfowl, we took the value for the 2004 – 2011 increase in bag of this species (12%) to represent the recent increase in bag for all gamebirds and waterfowl combined. Multiplying by the 2004 total of 19 million gives an estimated UK total for 2011 of 21.3 million gamebirds and waterfowl shot, excluding woodpigeons. PACEC (2006) reports that 3.6 million pigeons were shot, 'not as part of a job', in 2004 and that 53% of the total number of pigeons shot were killed not as part of a job. Hence, the estimated total number of pigeons shot is 6.8 million. Adding these to the total of other birds shot and assuming that the 2004 pigeon total also applies to 2011, gives a total of 28.1 million birds shot in 2011. This is a conservative estimate because we used the lowest of the four species estimates of the 2004 – 2011 increase in bag. Multiplying the species totals by mean body weights (from Snow and Perrins 1998) gives a total of 25,400 tonnes for the total annual weight of the bag of these quarry bird species. PACEC (2006) reported that 99% of the gamebirds and waterfowl and 90% of the pigeons were intended for human consumption. Using these proportions we estimated that the total annual unprocessed intact weight of gamebirds, waterfowl and pigeons intended for human consumption was 24,700 tonnes, derived from 27.3 million individual wild-shot birds. It seems probable that some of these birds were not used as food in the UK because their carcasses were rejected or because they were exported. The proportions of birds rejected and exported are unknown, as is the extent to which exports were compensated for by imports.

We estimated the mean weight of unprocessed gamebird carcasses required for a serving of a main course game meal using recipes published on the internet by the British Broadcasting Corporation (BBC n.d.). We used the number of birds required by the recipe and converted this into the weight of unprocessed bird carcasses required using body weights from Snow and Perrins (1998). In doing this, we took into account whether male or female birds were specified. We divided the total unprocessed weight of game required by the recipe by the number of portions this was said to provide. We avoided recipes which did not use the whole bird. We found ten eligible recipes for galliform gamebird meals (four pheasant, three partridge, three grouse *Lagopus lagopus*). The mean weight of unprocessed carcass per served portion was 499 g (1 SE = 56 g). Assumed values for the mass of a typical gamebird meal for an adult vary widely. EFSA (2010) assumed that an adult portion of game meat was 200 g, whereas FSA (2002) gives a value of 100 g. This suggests that between 20% and 40% of the unprocessed weight of a gamebird used for food is present in the resulting meal. Hence, based upon estimates of the numbers of wild-shot birds, we calculate that between 0.2 x 24,700 = 4,940 tonnes and 0.4 x 24,700 = 9,880 tonnes of gamebird meat has been eaten by UK consumers annually in recent years. This range overlaps the confidence interval of the value of 11,232 tonnes per year (95% C.L. 9,162 – 16,251) obtained from the gamebird meat consumption reported in the diet diary surveys from the NDNS.

Average *per capita* quantity of game meat consumed annually by high-level consumers of game in Scotland

We made an estimate of the mean number of meals including game meat consumed per week and per year by high-level consumers of game using a survey conducted by the Food Standards Agency in Scotland (FSAS 2012). This study reported a survey of game consumption rates derived from quantitative questionnaires administered to respondents during semi-structured interviews conducted in Scotland in 2011. People involved in the management and use of wild game were contacted and asked to participate in the study. These contacts included butchers, game dealers, members of shooting clubs, farmers, gamekeepers, beaters and gun shop proprietors. Respondents identified others known to them, who were not necessarily working in the same types of enterprises as the initial contacts, who ate wild game frequently and who were then also asked to participate. In total, 311 subjects were asked about their level of consumption of wild game and the interviews showed that 200 of these reported consuming wild game at least once per week during the shooting season. This level of consumption was taken by FSAS (2012) to represent the definition of a high-level consumer of wild game and our further calculations are only performed on the results from the 200 high-level consumers defined in this way.

Of the high-level consumers of wild game, 79% reported eating wild game once or twice per week during the shooting season and 21% ate wild game more frequently (three or more times per week) during the shooting season. All but two of the 200 high-level consumers also reported on their consumption of wild game outside the shooting season. Thirty-two percent of these high-level consumers reported eating wild game once or twice per week outside the shooting season and 9% ate wild game more frequently (three or more times per week) outside the shooting season. Raw data from the survey kindly provided to us by FSAS, show that 41% of high-level consumers reported eating wild game at least once per week throughout the year (both within and outside the shooting season) and 9% ate wild game at least three times per week throughout the year.

We used the raw data from the FSAS (2012) survey to make an estimate of the mean number of wild game meals consumed per week throughout the year by high-level consumers. To do this, it was first necessary to estimate the proportion of high-level consumers eating wild game during the shooting season on average 1.0 – 2.0 times per week, 2.0 – 3.0 times per week, and so on up to 6.0 – 7.0 times per week. We assumed that wild game was not eaten on more than seven occasions per week. Since the proportion of high-level consumers eating wild game on 1.0 – 3.0 occasions per week is much higher (79%) than the proportion eating game on 3.0 – 7.0 occasions per week (21%, see above), it seems plausible that the proportion of consumers eating game at each progressively higher number of occasions per week diminishes exponentially (*i.e.* by the same proportion) for each stepwise increase in consumption rate of one game meal per week. If this is the case, the proportions of high-level consumers eating wild game during the shooting season 1.0 – 2.0 times per week, 2.0 – 3.0 times per week, and so on up to 6.0 – 7.0 times would be 54%, 25%, 12%, 5%, 3% and 1% respectively. These proportions were obtained by calculating numerically the rate of exponential decline per occasion in the proportion of consumers in each one occasion per day category which would result in 79% being in the 1.0 – 3.0 occasions per week category and 21% being in the 3.0 – 7.0 occasions per week category. Outside the shooting season, the proportions of high-level consumers reporting wild game consumption in the categories never, less often than once a month, at least once a month, at least once a fortnight, at least once per week and three or four times per week or more are 20%, 6%, 26%, 16%, 31% and 1% respectively for consumers who ate wild game once or twice per week during the shooting season. The equivalent proportions of out-of-season consumption for consumers who ate wild game three or more times per week during the shooting season are 7%, 0%, 5%, 10%, 37% and 41% respectively. These results for consumption within and outside the shooting season were combined by converting them to mean daily consumption rates (game meals per day) for the two periods and multiplying by the number of days in the shooting season and outside it. For this purpose, the duration of the shooting season was taken to be 124 days, which is the season for pheasant shooting. Had the shooting seasons for all game animals been merged, their combined duration would have been larger than this. However, because pheasants comprise the majority of wild-shot birds eaten by people in the UK (PACEC 2006), adopting their season alone seems reasonable. Based upon these assumptions, the estimate of the mean consumption rate of wild game averaged over the whole year for the FSAS sample of high-level consumers was 1.64 game meals per week or 86 game meals per year. Confidence limits for this estimate were obtained by bootstrap resampling from the raw data provided by FSAS. We drew 10,000 bootstrap samples of 200 at random from the 200 real data and performed the same set of calculations upon each of the bootstrap sets as described above. We then took the values bounding the central 9,500 of these bootstrap estimates as the 95% confidence interval. The bootstrap 95% confidence interval for the estimated number of game meals eaten per week, year-round, is 1.49 – 1.84 meals per week. Hence, subject to the assumptions made about the duration of the shooting season and other issues, this survey provides reasonably precise estimates of the rate of consumption of game meals by this sample of high-level consumers in Scotland. If it is assumed that a typical game meal includes 200 g of meat (EFSA 2010), these per capita rates of consumption are equivalent to 17.1 kg per person per year (95% C.L. 15.5 – 19.2 kg) or 8.6 kg per person per year (95% C.L. 7.7 – 9.6 kg) if a game meal contains an average of 100 g of meat (FSA 2002). This compares with a *per capita* consumption rate of gamebird meat averaged across the whole UK population of 0.175 kg per person year, based upon the NDNS (see above). Hence, the amount of game meat eaten by high-level consumers is much higher, perhaps by two orders of magnitude, than the UK average. Had those NDNS subjects who ate gamebird meat during the 4-day diet diary period continued to eat it at the rate reported in the diary throughout the year, the annual *per capita* amount consumed by that subset of people would have been 7.0 kg per person per year (95% C.L. 5.7 – 8.2 kg).

Quantity of ammunition-derived lead in food eaten by humans in the UK

Previously it seems to have been supposed that exposure to elevated levels of dietary lead due to ingestion of meat from game shot with lead bullets and lead shot posed a minimal hazard to human health. This route of exposure is not mentioned in the Codex Alimentarius Code of Practice on reducing exposure to lead in food (Codex Alimentarius 2004). Ammunition-derived lead might not be eaten by consumers of game meat if nearly all of the mass of the projectiles striking the game animal remained in large pieces, which either passed through the carcass or were removed during food preparation or at the table. However, X-radiographic studies show that mammals and gamebirds shot with lead bullets and gunshot often contained lead fragments which were small, numerous and widely dispersed in edible tissues away from the wound canals. Results for large mammals killed using lead bullets come from X-ray studies of red deer *Cervus elaphus* (Knott *et al.* 2010), roe deer *Capreolus capreolus* (Knott *et al.* 2010) and white-tailed deer *Odocoileus virginianus* (Hunt *et al.* 2009, Grund *et al.* 2010). They indicate the presence of many small bullet fragments in the edible tissues of the carcass at distances up to 24 cm from the wound canal. Small fragments, which form a substantial proportion of fragment mass (Knott *et al.* 2010), were not removed by standard butchery practices on deer and fragments were found in both minced meat and steaks prepared for human consumption (Hunt *et al.* 2009).

Substantial fragmentation of lead shot also occurs when gamebirds and waterfowl are killed using gunshot. A UK study (Pain *et al.* 2010) found small fragments on X-rays in 76% of 121 gamebirds of six species examined. In this study wild-shot gamebirds obtained in the UK from selected supermarkets, game dealers or game shoots were X-rayed to determine the number of shot and shot fragments present. Most fragments were less than about a tenth of a shot in size. The small radio-dense particles sometimes appeared to follow the track taken by a shotgun pellet during passage through a bird, were sometimes clustered around bone, but sometimes appeared to be scattered throughout the bird. It was estimated that approximately 0.3% of the mass of lead in the gunshot considered to have struck gamebirds in their study would need to have fragmented into small particles to account for the concentrations of lead subsequently found in meals cooked using the gamebird meat. This reflects the lead remaining after all of the large fragments visible to the naked eye had been removed.

Studies of concentrations of lead in game meat also indicate that ammunition-derived lead is present in meat eaten by humans. Dobrowolska and Melosik (2008) measured lead concentrations in samples of muscle tissue from ten wild boar *Sus scrofa* and ten red deer shot with lead bullets. Lead concentrations in muscle tissue were elevated above the background level at up to 30 cm from the bullet track. Butchering and food preparation procedures on these boar and deer would require that a substantial proportion of muscle would have to be discarded if all tissue retained for human consumption was to have lead concentration within the limit set by the EU of 0.1 mg/kg for non-game meat (excluding offal). Lindboe *et al.* (2012) found that the mean concentration of lead in random samples of ground meat from moose *Alces alces* killed in Norway with lead-based bullets was 5.6 mg/kg.

Johansen *et al.* (2004) found that lead contamination of the meat of seabirds killed using lead shot occurred even though shot was removed after cooking. Pain *et al.* (2010) found a mean lead concentration of 1.181 mg/kg in meals prepared from 121 wild-shot gamebirds of six species, with no significant variation among species. Lead concentrations in the meals were statistically related to both the number of shotgun pellets and large fragments of lead removed before chemical analysis, and the number of small radio-dense fragments, detected by X-radiography of the gamebirds, which could not readily be removed. High concentrations of lead occurred in some meals prepared from birds in which no whole pellets or large fragments were apparent on X-rays. The only plausible mechanism for this is that lead particles remain in the meat after the removal of whole shot and large fragments.

An arithmetic mean concentration of 0.414 mg/kg (414 ppb) was found in twelve samples of pheasant meat purchased in the UK and reported in FSA (2007).

Many other data on concentrations of lead in game meat are summarised in EFSA (2010), but it is not clear whether or not visible shot and bullet fragments had been removed prior to analysis.

To protect human health, the European Commission sets maximum levels (MLs) for contaminants, including lead, in many foods (Commission Regulation 1881/2006)(EC 2006). The ML for lead in non-game meat (excluding offal) is 0.1 mg/kg, but no ML has been set for game meat. The results presented above show that lead concentrations in the meat of wild game animals shot with lead ammunition and eaten by humans are often one or two orders of magnitude higher than the non-game meat ML.

Bioavailability of ammunition-derived lead present in game meat and the effect of its ingestion on blood lead concentration

As described above, both lead shot and lead bullets fragment when fired into quarry animals and produce pieces of lead of a wide range of sizes which are embedded in the tissues. Some of these are at a considerable distance from the wound and remain after butchery and food preparation. Several studies indicate elevation in the concentration of lead in the blood (B-Pb) of people who eat game animals killed using lead ammunition, which indicates that some ingested ammunition-derived lead is absorbed (Bjerregaard *et al.* 2004, Johansen *et al.* 2006, Iqbal 2009, Dewailly *et al.* 2001, Bjermo *et al.* 2013, Meltzer *et al.* 2013, Knutsen *et al.* 2015). Analysis of stable isotope ratios of lead in blood samples indicates that exposure to ammunition-derived lead is the main cause of elevated blood lead (B-Pb) in indigenous people in Canada (Tsuji *et al.* 2008).

Hunt *et al.* (2009) performed an experiment on pigs to assess whether their B-Pb increased when they were fed on minced meat from deer shot with lead-based bullets. Statistically significant increases in their B-Pb were observed compared with controls fed on meat that contained no fragments. Mean blood lead concentrations in pigs peaked at 2.29 µg/dl two days following first ingestion of fragment-containing venison, which was 3.6 times higher than that of controls (0.63 µg/dl). Isotope ratios of lead in the meat matched those of the lead in the bullets used to shoot the deer, supporting the contention that the absorption by the pigs was of dietary lead derived from the ammunition.

These findings indicate that B-Pb of humans tends to increase in association with consumption of game meat containing ammunition-derived lead due to absorption of ammunition-derived lead from the alimentary canal. However, without further analysis, they do not indicate what proportion of the ammunition-derived lead ingested is absorbed or how much B-Pb is increased per unit of dietary lead ingested. Such estimates require either *in vitro* gastrointestinal simulation experiments which attempt to simulate conditions in the human alimentary canal or empirical studies in which both the intake of lead and the elevation of B-Pb are measured.

The absolute bioavailability of dietary lead derived from ammunition (the proportion of the ingested amount which is absorbed and enters the blood) might be expected to be lower than that of lead in the general diet because some of the ingested ammunition lead may remain as metallic fragments after cooking and processing in the alimentary canal. Metallic lead, especially that remaining in large fragments, may not be totally dissolved nor be absorbed in the intestine as readily as more soluble lead salts and complexes (Barltrop and Meek 1975, Oomen *et al.* 2003).

Mateo *et al.* (2011) used cooked meat from partridges killed with lead shot for *in vitro* gastrointestinal simulation experiments. They found that far more lead in the cooked gamebird meat was bioaccessible (soluble and available for absorption) in the simulated intestine phase when a recipe containing vinegar was used (6.75%) than when wine was used (4.51%) or than in uncooked partridge meat (0.7%). However, the reliability of estimates from *in vitro* gastrointestinal simulation experiments depends upon the uncertain degree to which the experiment mimics human digestion and absorption (Zia *et al.* 2011), and frequently-used cooking methods may vary between countries.

Because of these potential problems with *in vitro* estimates, Green and Pain (2012) used observations from two studies of Greenland adults (Bjerregaard *et al.* 2004, Johansen *et al.* 2006) to derive a quantitative empirical relationship between the mean daily intake of dietary lead from the meat of birds killed using lead shot and the mean concentration of B-Pb. There was a strong relationship in the data from both Greenland studies between mean B-Pb and the estimated mean rate of intake of dietary lead from meals of cooked wild bird meat. The regression models of Green and Pain (2012) indicated that the effect of ingested ammunition-derived lead on B-Pb was 39% lower than that expected for lead not derived from ammunition (Carlisle and Wade 1992). However, it should be noted that this regression method is subject to a known bias. Least squares regression assumes that the independent variable (in this case the dietary lead intake rate) is known without error. This is not the case because the intake rate means used were determined from sample estimates with attached errors which cannot be fully quantified and adjusted for. The direction of this bias on the slope of the fitted regression is negative, meaning that the true absolute bioavailability of lead may be larger than that estimated by this method.

There appear to be no published studies in which B-Pb was related to ingestion rates of ammunition-derived lead in children. The bioavailability of lead in the ordinary diet is considerably higher in children than in adults (Mushak 1998, IEUBK 2010).

Green and Pain (2012) assumed that the ratio of the absolute bioavailability of dietary lead from cooked wild bird meat to that of lead from the ordinary diet, calculated for adults (above), would be the same in children. As there is a widely-used value for the absolute bioavailability to children of lead from the ordinary diet (0.5, from Mushak 1998, IEUBK 2010), they estimated a value for absolute bioavailability in children of dietary lead derived from the cooked meat of wild birds of 0.3060. The same caveat about probable negative bias in this estimate applies as that described above for adults.

Effects of lead on human health and functioning

The consequences of exposure to lead for human health have been considered in great detail by the appropriate authorities of several countries. Lead affects the nervous, urinary, cardiovascular, immune, reproductive and other body systems and a range of organs, including the brain (USATSDR 2007, EFSA 2010). Experiments show that high doses of lead can induce tumours in rodents, and possibly humans, and the International Agency for Research on Cancer classified inorganic lead as 'probably carcinogenic to humans' (Group 2A) in 2006 (IARC 2006). Body systems particularly sensitive to low levels of exposure to lead include the haematopoietic, nervous, cardiovascular and renal systems (EFSA 2010).

Once lead has been absorbed into the body, its effects on health and functioning are largely independent of its original source. Hence, correlations between health outcomes and concentration of lead in tissues are an important source of information on effects of lead on health. The concentration of lead in whole blood is the most widely used measure of recent exposure, because of the short half-life of lead in the blood. Although measurements of lead concentrations in other tissues, such as bone, might be more informative about long-term exposure and chronic effects on health, sampling them is impractical and seldom possible. Hence, much of what is known about the health effects of lead is based upon correlations between health outcomes and B-Pb.

As evidence about the health effects of lead has accumulated and the sensitivity of analyses has increased, B-Pb concentrations shown to be associated with human health effects have correspondingly decreased. In addition, as human health concerns have resulted in regulations that have reduced human exposure from several previously important sources, such as occupational exposure, plumbing, paint and petrol additives, it has become possible to detect significant associations between health outcomes and B-Pb at much lower concentrations than would previously have been possible. Consequently, there has been a progressive decrease in the B-Pb concentrations proposed as thresholds for action and these are now one sixth or less of those considered as protective of human health in the

1960s (CDC 2005, 2012, Green and Pain 2012).

The removal of lead additives from vehicle fuel across Europe has resulted in a substantial decrease in lead absorbed through the lungs from the atmosphere. Today, the majority of lead exposure in the general population across the EU, including the UK, is from the diet (EFSA 2010). For decades, the principal approach of public health authorities to assessing health impacts of lead in the diet has been to identify a tolerable rate of dietary intake. This sought to maintain exposure below a no-observed-adverse-effect-level (NOAEL) that was assumed to exist. In 1982, the Joint Food and Agriculture Organisation/World Health Organisation Expert Committee on Food Additives (JECFA) set a Provisional Tolerable Weekly Intake (PTWI) of dietary lead of 25 µg/kg bw for infants and children This was extended to all age groups in 1993 and confirmed by JECFA in 1999. The PTWI was endorsed in 1992 by the European Commission's Scientific Committee for Food (SCF 1994). The European Commission carried out an updated lead exposure assessment in 2004 (SCOOP 2004) and together with the SCF opinion this formed the basis of setting Maximum Levels of lead in foodstuffs in the EU (Regulation (EC) No 1881/2006). However, today it is considered that there is no blood lead concentration below which negative physiological effects of lead are known to be absent (EFSA 2010, ACCLPP 2012). Hence, the concept of a tolerable intake level has been called into question. In 2007, the European Commission requested the European Food Safety Authority (EFSA) to produce a scientific opinion on the risks to human health related to the presence of lead in foodstuffs. In particular, EFSA was asked to consider new developments regarding the toxicity of lead, and to consider whether the PTWI of 25 µg/kg bw was still appropriate.

Following a detailed analysis of the toxicological information, the EFSA CONTAM Panel based their dose-response modelling on chronic effects in humans, and identified developmental neurotoxicity in young children and cardiovascular effects and nephrotoxicity in adults as the critical effects for the risk assessment. Several key findings are briefly summarised below with numerous individual studies fully referenced in EFSA (2010).

NEUROTOXICITY

A large number of studies have examined the relationship between B-Pb and measures of nervous system function in children and adults. Toxic effects of lead upon the nervous system in adults include impairment of central information processing, especially for visuospatial organisation and short-term verbal memory, psychiatric symptoms and impaired manual dexterity. There is also evidence that the developing brains of children are especially susceptible to the effects of lead exposure, even at low concentrations of lead.

A meta-analysis of the results of seven studies published between 1989 and 2003 of the IQ of 1,333 children in relation to B-Pb (Lanphear *et al.* 2005), and a refinement/reanalysis of the same data (Budtz-Jørgensen 2010) found marked decreases in IQ with increasing B-Pb, even at low B-Pb values. The effects of lead on the developing nervous system appear to persist, at least until late teenage years.

CARDIOVASCULAR EFFECTS

Long-term low-level exposure to lead is associated with increased blood pressure in humans. Meta-analyses support a relatively weak, but statistically significant, association between B-Pb levels and systolic blood pressure, amounting to an increase in systolic blood pressure of approximately 1 mm Hg with each doubling of B-Pb (Nawrot *et al.* 2002, Staessen *et al.* 1994), without any clearly identifiable B-Pb threshold for this effect.

NEPHROTOXICITY

A range of cross-sectional and prospective longitudinal studies have been conducted to examine the relationship between serum creatinine levels, which rise when kidney filtration is deficient, and B-Pb. Studies suggest an increased likelihood of chronic kidney disease as B-Pb levels rise, and the EFSA CONTAM Panel concluded that nephrotoxic effects are real, that they may be greater in men than women and that they are exacerbated by concurrent diabetes or hypertension.

The EFSA CONTAM Panel's analysis led to the conclusion that there is no evidence for a minimum B-Pb threshold below which effects on IQ, systolic blood pressure and chronic kidney disease do not occur. Hence, the NOAEL and PTWI approaches were not supported by evidence. Instead, the EFSA CONTAM Panel proposed the use of the Benchmark Dose (BMD) approach. The BMD is the B-Pb concentration associated with a pre-specified change in response (*i.e.* a specified loss of IQ, increase in systolic blood pressure, increased incidence of chronic kidney disease), the Benchmark Response (BMR).

The EFSA CONTAM Panel proposed BMRs that could have significant consequences for human health on a population basis (Table 1). These were: a 1% reduction in IQ (a one point reduction in

IQ) as the BMR for IQ, a 1% increase in systolic blood pressure (SBP) (equivalent to a 1.2 mm Hg change) as the BMR for cardiovascular effects; and a 10% increase in expected incidence of chronic kidney disease as the BMR for nephrotoxicity (EFSA 2010, Table 1). The JECFA PTWI was subsequently withdrawn in 2010/2011 (WHO 2007, JECFA 2010, WHO 2011).

Table 1: **Critical effects of lead, associated blood lead levels and corresponding dietary lead intake values** identified by the EFSA Panel on Contaminants in the Food Chain (CONTAM – EFSA 2010)

Benchmark Response (BMR)	**BMDL (95th percentile lower confidence limit of the benchmark dose – BMD of extra risk) derived from blood lead levels (µg/L)**	**Corresponding dietary lead intake value (µg/ kg bw per day)**	**Population level effects of BMR**
A 1% (1 point) reduction in IQ in young children	$BMDL_{01} = 12$	0.50	The BMR for IQ could impact the socioeconomic status of a population and its productivity. Studies in the USA have related a 1 point reduction in IQ to a 4.5% increased risk of failure to graduate from high school and a 2% decrease in productivity in later life (Schwartz 1994, Grosse *et al.* 2002).
A 1% increase in systolic blood pressure (SBP) in adults (equivalent to a 1.2 mm Hg change)	$BMDL_{01} = 36$	1.50	A 1% increase in SBP has been related to an increase in the percentage of the population treated for hypertension by 3.1%, and a 2.6% or 2.4% increase in expected annual mortality from cerebral stroke or myocardial infarction respectively (Selmer *et al.* 2000).
A 10% increase in expected incidence of chronic kidney disease in adults	$BMDL_{10} = 15$	0.63	

EFSA findings on the hazards to human health from dietary lead in Europe

The EFSA CONTAM Panel used the Integrated Exposure Uptake Biokinetic (IEUBK 2010) Model for lead in children (IEUBKwin version 1.1) and an equation from Carlisle and Wade (1992) for lead in adults to estimate the dietary intake of lead (BMD) required to produce the elevations in B-Pb associated with the BMR and also the BMDL, the lower one-sided 95% confidence bound of the BMDs (Table 1). This modification of the BMD allows for uncertainty in the dose-response relationship. They also assessed data on lead concentrations in foods in the European Union, including lead directly derived from ammunition in game meat. EFSA used information on lead concentrations in food and amounts of food eaten by individuals in participating countries to calculate mean ('average base diet') and 95th percentile ('high base diet') lead dietary exposures separately for each country. These exposure data were then used to produce corresponding B-Pb concentrations, and these were compared with the BMDLs to evaluate risk. In some assessments, groups of people frequently consuming game meat (defined as one 200 g meal per week of game) were considered separately. In calculating the effects upon B-Pb of game meat consumption the EFSA CONTAM Panel assumed that the bioavailability of dietary lead directly derived from ammunition was the same as for other sources of dietary lead. They obtained the ratio of dietary exposure, assuming various diets, to the BMDLs. The risk of

Benchmark Responses occurring was considered to be of particular concern if this ratio exceeded one.

The EFSA CONTAM Panel concluded that there was a potential risk[1] that some children in groups with average and high base diets could incur reductions of one IQ point as a result of exposure to dietary lead. Exposure to additional lead from frequent consumption of game, while not specifically evaluated, would further increase this risk in those exposed. The EFSA CONTAM Panel concluded that risk of cardiovascular effects as a result of exposure to lead was very low for adult average consumers across European countries. However, if exposure to dietary lead was closer to the upper end of the range in adult high consumers, the potential exists for some consumers to have increased systolic blood pressure as a result of exposure to lead. For nephrotoxicity, the EFSA CONTAM Panel concluded that it is possible some consumers at the high and low end of the exposure ranges could potentially incur chronic kidney disease as a result of exposure to dietary lead.

For consumers of an average base-diet, but also with frequent consumption of game meat, the CONTAM Panel concluded that there was a potential risk that some people could incur cardiovascular and nephrotoxic effects as a result of exposure to lead. This risk is increased over people not frequently consuming game due to the relatively high lead levels in game.

In their summary conclusions, the EFSA CONTAM Panel considered that [for the population in general] at current levels of lead exposure there is only a low to negligible risk of clinically important effects on either the cardiovascular system or kidneys of adult consumers. However, in infants, children and pregnant women, there is potential concern at current levels of exposure to lead for effects on neurodevelopment.

Frequent consumption by these most vulnerable groups of game shot with lead ammunition would obviously increase exposure.

Effects of lead on human health not assessed by EFSA

Green and Pain (2012) also assessed studies of effects of lead on Standard Assessment Test (SAT) scores of UK schoolchildren and in rates of spontaneous abortion in pregnant women in Mexico, which were not evaluated by EFSA. The SAT score study (Chandramouli *et al.* 2009) was not published in time to be evaluated by EFSA, whilst the spontaneous abortion study by Borja-Aburto *et al.* (1999) was available but not mentioned in EFSA (2010).

Chandramouli *et al.* (2009) reported a negative association of academic test results of UK schoolchildren at Key Stage 1 (SATs) with B-Pb measured at 30 months of age. Green and Pain (2012) used the relationship between the mean outcome of the SATs writing test and blood lead to estimate the reduction in the test score expected from a specified increase in B-Pb. EFSA (2010) did not calculate a BMR for SATs scores. However, EFSA (2010) defined the BMR for IQ as 1 IQ point, which is one-fifteenth of the population standard deviation for IQ. To calculate an equivalent change in SATs KS1 writing score to that identified as the BMR for IQ, we obtained the maximum-likelihood mean and standard deviation of SATs scores for children in England in 2010 (Department for Education 2013). The calculated values were 1.90 SATs grade points for the mean and 0.60 SATs grade points for the standard deviation, where the SATs grades run from 0 (working towards Level 1) to 4 (Level 4). Hence, we took the equivalent BMR for the SATs KS1 writing grade score to that used by EFSA (2010) for IQ to be 0.60/15 = 0.04 SATs grade points.

Green and Pain (2012) used a statistical model fitted by Borja-Aburto *et al.* (1999) to describe the relationship between B-Pb and the proportion of pregnant women in Mexico City who incurred spontaneous abortion. The model adjusted for the effect of a previous history of spontaneous abortion. EFSA (2010) did not evaluate this study or calculate a Benchmark Response (BMR) for spontaneous abortion.

Potential risks to humans in the UK from ammunition-derived lead

Green and Pain (2012) used data on lead concentrations in UK gamebirds, from which gunshot had been removed following cooking to simulate human exposure to lead (Pain *et al.* 2010). They combined this with UK food consumption and lead concentration data to evaluate the number of gamebird meals (of 200 g for adults; 118 g for a 6.9 year old and 100 g for a 2.5 year old child) consumed weekly that would be expected, based upon published studies, to result in specified changes, over and above those resulting from exposure to lead in the base

[1] Where we have described groups potentially at risk of incurring critical effects the specific terminology used by EFSA is generally that 'the possibility of an effect cannot be excluded' (EFSA 2010).

diet, in IQ, systolic blood pressure and chronic kidney disease. As described above, these health effects were considered in the opinion of the EFSA CONTAM Panel (EFSA 2010) to be significant at a population level. Green and Pain (2012) also used the same approach to evaluate potential effects of consumption of gamebird meat on SAT scores and in rates of spontaneous abortion, which were not assigned BMRs by EFSA.

The results indicated the potential for the consumption of 40 - 70 g of gamebird meat per week to be associated with a 1 point decrease in the IQ of children, the BMR identified by EFSA (2010), with the two values being for Green and Pain's regression estimate of bioavailability and the standard bioavailability values as used in IUEBKwin.

For the present study, we estimated a potential risk of change in children's SATs writing tests scores equivalent to the EFSA BMR for IQ in children (see above) for those that consume 12.7 to 20.4 g of gamebird meals per week. Amounts of game that adults would need to consume to be at potential risk from an arbitrary 1% increased risk of spontaneous abortion (women), and from the EFSA BMRs for chronic kidney disease and systolic blood pressure are presented in Table 2.

Table 2: **Numbers of people in the UK calculated to be at potential risk of incurring threshold health or function effects of ammunition-derived lead from gamebirds** assuming two values of the bioavailability of lead from ammunition and consistent rates of consumption of gamebird meals throughout the year.

			High bioavailability			**Low bioavailability**		
Health/function outcome	**Critical response**	**Age class**	**Threshold intake rate g/week**	**No. affected**	**95% C.L.**	**Threshold intake rate g/week**	**No. affected**	**95% C.L.**
IQ	Deficit of 1 IQ point*	Children < 8 years	40	38126	16704 - 63012	70	28710	12684 - 47846
SATs writing score	Deficit of 0.04 score point	Children < 8 years	12.7	47926	20072 - 79495	20.4	45427	19346 - 75507
Spontaneous abortion rate	Increase in risk by 1%	Women 18-45 years	560	10977	5432 - 17157	920	3505	1333 - 6259
Chronic kidney disease Model 1	Increase in risk by 10%*	Adults > 18 years	240	235898	151954 - 319277	380	112158	64637 - 162612
Chronic kidney disease Model 2	Increase in risk by 10%*	Adults > 18 years	800	23713	9920 - 40652	1300	6749	2045 - 13965
Systolic blood pressure	Increase by 1.2 mmHg*	Adults > 18 years	640	39584	18369 - 64640	1040	12320	4342 - 23273

Critical responses marked * are Bench Mark Responses (BMR) defined by EFSA (2010). Two models for calculating the BMR for kidney disease were used: Model 1 is that used by EFSA(2010) and Model 2 is that proposed by Green and Pain (2012) to allow for confounding variables.

A limitation of this study is that Green and Pain (2012) estimated BMDs but did not estimate BMDLs, as was done by EFSA (2010). This is because of the difficulties associated with including uncertainties in the additional elements used in their calculations, such as bioavailability. Had BMDLs been calculated they would have indicated that consumption of smaller quantities of gamebird-derived meals would result in BMDL doses than those resulting in the BMD doses.

We used the results of analyses of national diet data from the NDNS (as described earlier) and UK population data for 2013 to estimate maximum numbers of individuals in the UK exceeding the threshold intake rates of gamebird meat required to be at potential risk from incurring critical responses (see Table 2). We used the number of children less than 8.0 years old as the group at potential risk from incurring IQ and SATs effects. We used the number of women in the age range 18.0 to 45.0 years old as the group at potential risk from incurring the spontaneous abortion effect and did not attempt to allow for the proportion that were pregnant. The estimates are maxima because we assumed that the proportion of people consuming gamebird meals and the distribution of amounts consumed per four-day period were constant throughout the year and as specified by analyses of the data shown in Figures 1 and 2. Although there may be some consistency over time in game consumption, its magnitude is unknown. If consumers did not eat game consistently through the year at the rates indicated by the NDNS survey, the number of consumers would be larger than our estimates but the average amount eaten per consumer would be smaller. The net result would be a reduction in the numbers of people with gamebird meal intakes exceeding those required to be at potential risk of the critical responses.

The maximum numbers shown in Table 2 indicate the potential for tens of thousands of UK children to have gamebird meal intakes exceeding those required to be at potential risk from incurring the critical responses for IQ and SATs scores. Maximum numbers of adults exceeding threshold intake rates for potential risk of incurring cardiovascular, nephrotoxicity and spontaneous abortion critical responses tended to be smaller, being hundreds or thousands. The exception was for the chronic kidney disease critical response as defined by the dose-response model used by ESFA (2010). This model indicated that over one hundred thousand people might exceed the threshold intake rate. However, as noted by Green and Pain (2012), this dose-response model did not allow for potential confounding variables and may overestimate effects. The alternative model proposed by Green and Pain (2012) allows for confounding variables and gives smaller maximum numbers (Table 2).

Recognising that the results shown in Table 2 are maxima, we also calculated equivalent minimum values using independent data. We used the results of an unpublished survey of the shooting community in the UK conducted by the British Association for Shooting and Conservation (BASC) and the Countryside Alliance (CA), which is cited in LAG (2014). The survey estimated that about 9,000 (midpoint of range 5,500-12,500) children under 8 years old and about 44,500 adults (midpoint of range 27,000 - 62,000) from the shooting community consume at least one game meal per week averaged over the year. This estimate refers to all types of game, but, as most game in the UK is shot using lead ammunition, it is likely that the vast majority of the game meals reported by members of the shooting community were made using wild gamebirds killed using lead ammunition.

We used the estimates of the threshold intake rates of gamebird meat required to be at potential risk of incurring the critical responses from Table 2 in combination with the LAG (2014) estimates of numbers of high-level consumers analyses of game in the UK and the results of the FSAS (2012) survey of the distribution of numbers of game meals eaten per week by high-level game consumers in Scotland to estimate minimum numbers of individuals in the UK potentially exceeding the thresholds (Table 3). We used the number of children less than 8.0 years old as the group at potential risk from incurring IQ and SATs effects because this is the age group used in the survey results cited in LAG (2014). We assumed that the proportion of adult high-level consumers who were women in the age range 18.0 to 45.0 years old was the same as for all UK adults in 2013. Because the rates of consumption of game in the FSAS (2012) and LAG (2014) surveys were in meals per week rather than weights of meat, it was necessary to assume an average meal size. We used the values used by Green and Pain (2012), based upon the 200 g game meal size for adults used by EFSA (2010) and also the lower values (30 g for children, 100 g for adults) for gamebird meals from FSA (2002). We used bootstrap resampling of the FSAS (2012) survey data, as described previously, to estimate uncertainty in the numbers. From each bootstrap replicate, a non-parametric cumulative distribution of numbers of game meals per year was constructed and proportions of subjects exceeding a specified threshold were obtained by linear interpolation.

Table 3: **Numbers of UK high-level consumers of game from the shooting community calculated to be at potential risk** of incurring threshold health or function effects from ingestion of ammunition-derived lead from gamebirds under various assumptions about game meal size and bioavailability of lead from ammunition**.**

				Small meal size					**Large meal size**				
					High bioavailability		**Low bioavailability**			**High bioavailability**		**Low bioavailability**	
Health/function outcome	Critical response	Age class	No. high-level consumers	Meal size (g)	No. affected	95% C.L.	No. affected	95% C.L.	Meal size (g)	No. affected	95% C.L.	No. affected	95% C.L.
IQ	Deficit of 1 IQ point*	Children <8 years	9000	30	5124	4382 - 5602	3800	3053 - 4374	118	>9000	>9000 - >9000	>9000	>9000 - >9000
SATs writing score	Deficit of 0.04 score point	Children <8 years	9000	30	>9000	>9000 ->9000	8040	7668 - 8328	100	>9000	>9000 - >9000	>9000	>9000 - >9000
Spontaneous abortion rate	Increase in risk by 1%	Women 18-45 years	10154	100	886	312 - 1245	0	0 - 0	200	2267	1601 - 2800	926	476 - 1313
Chronic kidney disease Model 1	Increase in risk by 10%*	Adults >18 years	44500	100	18052	14498 - 2085	4561	2634 - 6434	200	28361	24739 - 30825	19402	15671 - 22091
Chronic kidney disease Model 2	Increase in risk by 10%*	Adults >18 years	44500	100	0	0 - 0	0	0 - 0	200	4314	2381 - 6110	438	185 - 744
Systolic blood pressure	Increase by 1.2 mmHg*	Adults >18 years	44500	100	578	248 - 969	0	0 - 0	200	6479	4139 - 8589	3962	1716 - 5601

Critical responses marked * are Bench Mark Responses (BMR) defined by EFSA (2010). Two models for calculating the BMR for kidney disease were used: Model 1 is that used by EFSA (2010) and Model 2 is that proposed by Green and Pain (2012) to allow for confounding variables. Numbers of high-level consumers are the mid-points of the ranges for children and adults from the shooting community estimated by a BASC/CA survey (LAG 2014) to eat at least one game meal per day throughout the year. The number of women at potential risk of spontaneous abortion is the number of child-bearing age obtained by multiplying the BASC/CA adult total by the proportion of adults in the 2013 UK population who are women in the age range 18-45 years. Small meal sizes are from FSA (2007) and large meal sizes from Green and Pain (2012) (children) and EFSA (2010) (adults).

The minimum numbers shown in Table 3 indicate that thousands of UK children from the shooting community may have gamebird meal intakes exceeding those required to be at potential risk from incurring the critical responses for IQ and SATs scores. Maximum numbers of adults from the shooting community estimated to exceed threshold intake rates for potential risk from incurring cardiovascular, nephrotoxicity and spontaneous abortion critical responses tended to be much smaller, ranging between zero and hundreds or thousands. As was the case for the maxima in Table 2, the exception was for the chronic kidney disease critical response from the dose-response model used by EFSA (2010). The same comment applies to this result as was made for the maxima.

CONCLUSIONS

People in the UK can be exposed to lead from ammunition principally by ingestion of dietary lead derived from small fragments of lead shot or bullets in game meat and the absorption of lead in the alimentary tract. Mean lead concentrations in meat from both large and small game animals shot with lead ammunition are often elevated, and frequently considerably elevated above the levels considered acceptable for meat derived from the muscle tissue of non-game animals. Some ammunition-derived dietary lead from the tissues of game animals ingested by humans is absorbed in the alimentary tract and enters the bloodstream. The absolute bioavailability of ammunition-derived lead may be lower than that of lead in the general diet, but the extent to which this is the case is unclear. However, the minimum plausible value of absolute bioavailability of ammunition-derived lead is substantial and capable of causing elevation of blood lead concentrations thorough absorption of ammunition-derived dietary lead.

At least one million people in the UK consume wild game at least once per year and surveys indicate that at least tens of thousands of people from the shooting community are high-level consumers of wild-shot game. The mean frequency of consumption of game meat by these high-level consumers may exceed one game meat meal per week, averaged over a whole year. There may be some high-level consumers outside the shooting community who are not included in these estimates. Many more people consume game less frequently.

There is no known requirement for lead by humans and no evidence for a threshold of exposure such as dietary intake rate or of blood lead level below which lead-induced negative health effects, such as increased systolic blood pressure, risk of chronic kidney disease and reduction in IQ score, can be considered to be completely absent.

Our calculations of minimum and maximum numbers of people in the UK exceeding threshold intake rates of gamebird meat required to be at potential risk of incurring the critical health effects identified by EFSA (2010) and Green and Pain (2012) indicate that children are likely to be the most numerous group vulnerable to negative effects on cognitive development from exposure to ammunition-derived lead. It is estimated that thousands of children in the UK (calculated to be in the range 4,000 - 48,000) could be at potential risk of incurring a one point or more reduction in IQ as a result of current levels of exposure to ammunition-derived dietary lead. Numbers of adults potentially vulnerable to critical health effects appear to be smaller, but the available data are too sparse to be certain.

In accord with these conclusions, the UK Food Standards Agency (FSA 2012) have advised that frequent consumers of game shot with lead ammunition should eat less of this type of meat, and that this is especially important in the case of toddlers and children, pregnant women and women trying for a baby, because of the harm that lead can cause to the brain and developing nervous system. This is consistent with recent advice given following risk assessments by equivalent agencies in a range of other European countries who consider that these most vulnerable groups should eat little or no game shot with lead ammunition (Germany, Spain, Sweden and Norway, see Knutsen *et al.* 2015).

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X-ray of a wood pigeon *Columba palumbus* sold by a game dealer: note the tiny radio-dense lead particles which would go unnoticed by the consumer.

Photo Credit: WWT