

Assessment of selenium intake using data from the UK National Diet and Nutrition Survey: Methodological challenges

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ABSTRACT

Background: Concerns have been raised about the adequacy of dietary selenium (Se) intake in the UK population in recent years, but because the safe intake range is narrow, it is important to be able to measure intakes as accurately as possible.

Methods: We assessed Se exposure in UK adults by comparing reported dietary intakes from the National Diet and Nutrition Survey (NDNS) with estimated intakes from plasma Se concentrations obtained from the European Food Safety Authority (EFSA) model. For the purpose of this study, we used NDNS data on UK adult population divided in the two periods 1–11 and 12–15 years, carried out in 2008–2019 and 2019–2023. We assessed Se exposure in plasma and compared dietary intake from NDNS (Se-NDNS) with the plasma-derived EFSA estimates (Se-EFSA).

Results: Mean plasma Se concentrations were higher in years 12–15 compared to years 1–11 (95.54 vs 81.33 µg/L). Dietary intakes in the first period were similar for both Se-NDNS and Se-EFSA (46.79 vs. 47.28 µg/day), whereas in the most recent period Se-EFSA yielded higher levels compared to Se-NDNS estimates (69.19 vs 43.47 µg/day). The relation between Se-NDNS and Se-EFSA was non-linear and differed by survey period, with greater variability and imprecision in plasma-derived estimates, particularly at higher intakes and in the most recent survey years. Associations were substantially similar between sex and age groups.

Conclusions: Our findings suggest a potential underestimate of Se exposure based on Se-NDNS dietary assessment, but also show methodological limitations and uncertainties in modelling Se intake from plasma concentrations. These results support the need to refine methods in order to make full use of biomarkers to assess Se exposure and draw conclusions about the adequacy of dietary reference values for Se, including the current UK ones.

1. Introduction

Selenium (Se) is a trace element characterized by both nutritional and toxicological properties with a narrow range of intake recommended to avoid symptoms of deficiency and excess, which in turn are still partially undefined and under active investigation [1–6]. Furthermore, its safe exposure range is highly debated for a number of reasons,

including the endpoints used to determine dietary requirements, excess and deficiency, the uncertainties and inconsistencies of epidemiologic studies, the reliability of the methods employed to assess dietary intake, and the different impact of the chemical species of the element [7–9].

Several biomarkers have been proposed and assessed to measure Se exposure. Plasma and serum concentration levels are the most widely accepted to evaluate short-term exposure, whilst nail concentrations of

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Se have been proposed for long-term exposure, despite some limitations especially their variability over time [10,11]. Urinary Se excretion is another potentially useful indicator [11], although potentially affected by relevant limitations [12]. Alternatively, levels and activity of selenoproteins, especially selenoprotein P (SEPP1) and glutathione peroxidases (GPx) have been proposed and used to assess adequacy of Se exposure and set the reference dietary requirements [7,13,14].

In addition to biomarkers, a direct assessment of habitual Se dietary intake has been performed by using food records and food frequency questionnaires. However, the latter approach has substantial limitations, due to the high variation of Se content within similar foods which may markedly vary, inaccuracies in the determination of Se content, changes in Se availability in foods, and the occurrence of recall bias during the dietary assessment [15–18].

Therefore, the relation between plasma/serum Se and dietary intake has long attracted attention, also aiming at determining the latter based on the former [19–23]. For steady state plasma Se concentrations below 120 µg/L, an increase in the mean daily dietary intake of 1 µg of natural Se results to equate to a mean increase in plasma/serum concentration of about 1.5 µg/L, according to a pooled analysis published in 1996 [19]. A further and much more recent examination of this relation undertaken by the European Food Safety Authority (EFSA) during the reassessment of the tolerable upper intake level of Se, suggested a non-linear relation between Se intake and blood levels [2], with two best fitting linear models depending on plasma/serum concentrations, the first with a steeper slope up to 70 µg of daily intake, and the second one with a much less steep slope at higher intakes.

In 1991, the UK Committee on Medical Aspects of Food and Nutrition Policy (COMA) established 75 µg/day as Reference Nutrient Intake (RNI) for Se, corresponding to approximately 100 µg/Se/L, being this amount the one at which GPx activity is maximized and reaches a plateau [24]. The Lower Reference Nutrient Intake (LRNI), i.e. the level which meets the requirements for only 2.5% of the population, calculated as two standard deviations below the estimated average requirement, was set at of 40 µg/day [24]. In 2013, the UK Scientific Advisory Committee on Nutrition (SACN) report on Se [25] noted that 39% of adults aged 19–64 years and 42% of older adults (65 years and over) had Se intakes below the LRNI of 40 µg/day [24]. Furthermore, it has been suggested that Se intake fell in more recent years, possibly due to the declining use of North American wheat flour in the UK, and the corresponding increase in European flours, which contain less Se [26]. As a result of concern over the apparent too low intakes of Se, SACN reviewed research findings on associations between Se and a range of health outcomes but found no adverse health consequences of dietary intakes at the levels typically seen in the UK, or alternatively convincing evidence of benefits of higher intakes. Nevertheless, two key questions were raised by SACN [27]: (1) is Se intake in the UK measured by dietary assessment underestimated?, and (2) is the LRNI set at an inappropriately high level? In the present study, our aim was to examine both issues, by comparing data from the Se intake derived from Se plasma concentrations and direct assessment of Se dietary intake available within the National Diet and Nutrition Survey (NDNS) [28].

2. Methods

2.1. Study population

We used cross-sectional data from the National Diet and Nutrition Survey (NDNS) assessing Se levels in plasma and daily dietary intake. For NDNS years 2008–2013, ethical approval was obtained from the Oxfordshire A Research Ethics Committee (Ref. No. 07/H0604/113), for NDNS 2014–2023 the approval was received from the Cambridge South NRES Committee (Ref. No. 13/EE/0016). This study has been registered in the UK Data Service (projects no. 246359 and 282534). Informed consent was obtained from every participant. NDNS Rolling Programme conforms to the Declaration of Helsinki and operates under UK National

Health Service. Details of selection, recruitment, sample analysis and dietary assessment have been reported elsewhere [29,30]. For the purpose of this study, we used NDNS data divided in the two periods 1–11 and 12–15 years, carried out in 2008–2019 and 2019–2023, because of some changes in the methodology including modality of dietary assessment and blood collection and analysis [31,32]. In NDNS years 1–11, survey participants were asked to complete diary records with information of all foods and drinks at home and outside over four consecutive days in order to include both working days and weekend. To help the completion of portion sizes, photographs of most frequently consumed foods were provided [30]. In NDNS years 12–15, survey participants were asked to complete multiple non-consecutive 24-hour dietary recalls using online Intake24, a tool with automatic assignment of food codes and weights in grams to the foods and portion sizes selected by participants [32,33].

Intakes of foods estimated through diaries or recalls (in g/day) were multiplied with the measurements of Se content in foods (µg/g). In both periods, foods with the highest Se content were offal (e.g. kidney), Brazil nuts, fish (e.g. tuna), while foods most contributing to intake are meat and meat products (29%), cereals and cereal products (27%), fish and fish dishes (16%) [34].

In the present study, we focused on the adult population which assessed both dietary Se intake and plasma concentrations. Overall, a total number of 15,655 individuals (years 1–4: 6828 individuals; years 5–6: 2546 individuals; years 7–8: 2723 individuals; years 9–11: 3558 individuals) were recruited during years 1–11 and 4370 individuals were recruited during years 12–15 (Fig. 1). We excluded subjects with missing analysis of plasma Se ($N = 13,693$), non-adult population aged < 18 years, and subjects taking Se supplements (> 5 µg/day) ($N = 395$), as the chemical form of supplemented Se may not fully represent dietary Se and therefore may not fit the model derived to estimate intake from plasma Se concentration.

2.2. Estimation of Se intake and data analysis

For the estimation of Se intake from plasma levels we used the model developed by EFSA [2] indicating a relation that is not entirely linear. The proposed model is comprised of two linear models with different steepness of slope, derived from two different, consecutive ranges of exposure below and above 110.6 µg Se/L in plasma (approximately 70 µg/day), with the corresponding equations:

$$< 110.6 \text{ µg Se/L: } \text{Se}_{\text{plasma}} = 23.1 \text{ (95\% CI 1.92-44.28)} + 1.25 \text{ (95\% CI 0.88-1.61)} \text{ Se}_{\text{intake}} \quad (1)$$

$$\geq 110.6 \text{ µg Se/L: } \text{Se}_{\text{plasma}} = 79.9 \text{ (95\% CI 58.72-101.08)} + 0.43 \text{ (95\% CI 0.29-1.58)} \text{ Se}_{\text{intake}} \quad (2)$$

Therefore, we estimated Se intake with the following equations using as turning point the value of 70 µg/day, respectively (3) below and (4) above or equal to the cutpoint:

$$\text{Se}_{\text{intake}} = (\text{Se}_{\text{plasma}} - 23.10)/1.25 \quad (3)$$

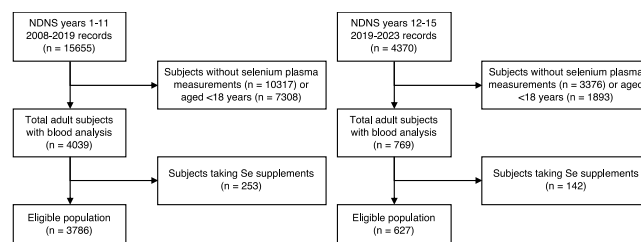


Fig. 1. Flow-chart of participant selection for the National Diet and Nutrition Survey (NDNS) years 1–11 and 12–15, carried out in 2008–2019 and 2019–2023 periods.

Correlation of the Se intake derived from plasma using the model is reported in [Supplementary Figure S1](#), showing calibration fit and 95% confidence intervals using the model uncertainty [2].

We then assessed the association between Se intakes assessed from dietary data by NDNS (Se-NDNS) and Se intake estimated by applying the EFSA model (Se-EFSA) to Se plasma concentrations in the same survey participants. We non-linearly modelled such association using restricted cubic spline models with three knots at fixed percentiles (10th, 50th, and 90th), adjusting for potential confounders including age, sex, smoking status and energy intake. We ran the analysis for the overall population and stratified by sex and age groups (<65/≥65 years).

We report descriptive data using mean, standard deviation (SD) and percentiles (5th, 25th, 50th, 75th, 95th). We used *regress*, *mkspline*, and *xbrcspline* routines of StataNow 19.5 MP-Parallel Edition (StataCorp. LLC, College Station, TX, 2025) to perform all data analyses.

3. Results

We eventually included 3786 participants from years 1–11 and 627 participants from years 12–15 in our study. Subjects' characteristics are reported in [Table 1](#): mean age was little lower in years 1–11 compared to 12–15 (49.6 vs 53.9 years), but with no difference by sex. Secondary school was the most common educational attainment level, although the proportion was much higher in years 1–11 compared to 12–15. As regards smoking status, we found a slightly lower proportion of never smokers in years 1–11 compared to years 12–15 (55.3% vs. 62.0%), in both periods higher in females than males. Current smokers decreased

from years 1–11 (20.3%) to years 12–15 (12.6%), with similar trends in both sexes. Mean energy intake was 1798 kcal/day in years 1–11, while little lower 1643 kcal/day in years 12–15, in both periods higher in males than females.

Distribution of Se plasma levels in the study population are reported in [Table 2](#) showing higher levels in years 12–15 compared to years 1–11 (95.54 vs 81.33 µg/L) in the overall population as well as in stratified analyses divided by sex and age.

Distribution of Se estimates based on NDNS dietary assessment and on the EFSA model applied to NDNS plasma Se levels are reported in [Table 3](#) for overall subjects and main subgroups. For all subjects, in years 1–11 the NDNS estimates and EFSA predicted mean values were similar or slightly higher for EFSA estimates (46.79 vs. 47.28 µg/day), while in years 12–15 the EFSA predicted values were much higher than the NDNS estimates (69.19 vs 43.47 µg/day). Comparison of Se-NDNS estimates in years 1–11 and 12–15 showed a very slightly lower intake in years 12–15, whilst Se-EFSA estimates from plasma showed the opposite, with higher values in years 12–15 and a somewhat different distribution with a trend towards higher predicted intakes ([Fig. 2](#)). The plasma concentrations were also higher in years 12–15 than years 1–11 ([Table 2](#)). Comparison of Se estimates from NDNS and Se-computed intakes using the EFSA model showed marked differences according to the study periods. In years 1–11 higher intakes using the EFSA model at 'low' measured intakes (≤median value), whereas at higher NDNS intakes, the predicted intakes from the EFSA model appear to be somewhat lower. In years 12–15, we found higher estimates of Se intake using the EFSA model compared with the dietary NDNS assessment, across the

Table 1
 Characteristics of National Diet and Nutrition Survey (NDNS) participants in the 1–11 and 12–15 year periods.

	Years 1–11	Years 1–11	Years 1–11	Years 12–15	Years 12–15	Years 12–15
	Total subjects (n = 3786)	Males (n = 1616)	Females (n = 2170)	Total subjects (n = 627)	Males (n = 304)	Females (n = 323)
Age						
Mean (SD)	49.6 (17.0)	49.6 (17.1)	49.6 (17.0)	53.9 (17.7)	53.7 (17.1)	54.1 (17.4)
< 65 years	2979 (78.7)	1272 (78.7)	1707 (78.7)	432 (68.9)	212 (69.7)	220 (68.1)
≥ 65 years	807 (22.3)	344 (21.3)	463 (21.3)	195 (31.1)	92 (30.3)	103 (31.9)
Education						
Secondary school	2563 (67.7)	1070 (66.2)	1493 (68.8)	353 (56.3)	148 (49.0)	204 (63.2)
Above secondary school	1084 (28.6)	478 (29.6)	606 (27.9)	256 (40.8)	145 (47.7)	111 (34.4)
Currently full-time education	116 (3.1)	59 (3.6)	57 (2.6)	12 (1.9)	7 (2.3)	5 (1.5)
Foreign or others	23 (0.6)	9 (0.6)	14 (0.7)	6 (1.0)	3 (1.0)	3 (0.9)
Marital status						
Single	1063 (28.1)	485 (30.0)	578 (26.6)	176 (28.1)	88 (29.0)	88 (27.2)
Married/living with partner	1842 (48.7)	853 (52.8)	989 (45.6)	344 (54.9)	166 (54.6)	178 (55.1)
Separated/divorced	702 (18.5)	225 (13.9)	477 (22.0)	107 (17.1)	50 (16.4)	57 (17.7)
Widowed	179 (4.7)	53 (3.3)	126 (5.8)	0 (0.0)	0 (0.0)	0 (0.0)
Ethnic group						
White	3540 (93.5)	1509 (93.4)	2031 (93.6)	577 (92.0)	280 (92.1)	323 (92.0)
Mixed ethnic group	33 (0.9)	9 (0.6)	24 (1.1)	4 (0.6)	0 (0.0)	4 (1.2)
Black or Black British	55 (1.4)	26 (1.6)	29 (1.3)	19 (3.0)	8 (2.6)	11 (3.4)
Asian or Asian British	118 (3.1)	54 (3.3)	64 (3.0)	20 (3.2)	11 (3.6)	9 (2.8)
Any other group	40 (1.1)	18 (1.1)	22 (1.0)	7 (1.1)	5 (1.6)	2 (0.6)
Occupation						
Full-time or part-time	2145 (56.7)	985 (61.0)	1160 (53.5)	352 (56.1)	175 (57.6)	177 (54.8)
Not working at survey interview	1500 (39.6)	568 (35.1)	932 (42.9)	258 (41.2)	118 (38.8)	140 (43.3)
Going to school	141 (3.7)	63 (3.9)	78 (3.6)	17 (2.7)	11 (3.6)	6 (1.9)
Income						
Not applicable	482 (12.7)	181 (11.2)	301 (13.9)	79 (12.6)	34 (11.2)	45 (13.9)
< 17,500 £GBP	1021 (27.0)	395 (24.4)	626 (28.9)	143 (22.8)	62 (20.4)	81 (25.1)
> 17,500, ≤ \$32,383 £GBP	1044 (27.6)	444 (27.5)	600 (27.6)	182 (29.0)	78 (25.7)	104 (32.2)
> 32,383 £GBP	1239 (32.7)	596 (36.9)	643 (29.6)	223 (35.6)	130 (42.8)	93 (28.8)
Smoking						
Never regular smokers	2095 (55.3)	833 (51.5)	1262 (58.2)	389 (62.0)	180 (59.2)	209 (64.7)
Ex-regular cigarette smokers	909 (24.0)	427 (26.4)	482 (22.2)	131 (20.9)	69 (22.8)	62 (19.2)
Current cigarette smokers	769 (20.3)	347 (21.5)	422 (19.4)	79 (12.6)	44 (14.5)	35 (10.8)
Missing	13 (0.3)	9 (0.6)	4 (0.2)	28 (4.5)	11 (3.6)	17 (5.3)
Mean (SD) energy intake						
Total energy MJ/day	7.56 (2.33)	8.70 (2.43)	6.71 (1.82)	6.90 (2.05)	7.75 (2.14)	6.11 (1.60)
Total energy kcal/day	1797.6 (554.3)	2070.4 (579.8)	1594.5 (434.9)	1642.5 (488.5)	1843.8 (509.7)	1452.9 (381.1)

Abbreviations: GBP, pound sterling; MJ, megajoule; SD, standard deviation.

Table 2
Plasma selenium (Se) concentration (µg/L) distribution in National Diet and Nutrition Survey (NDNS) participants divided survey periods (years 1–11 and 12–15). SD: standard deviation (SD).

	Mean	SD	5th	25th	50th	75th	95th
All subjects							
Se-NDNS years 1–11	81.48	15.15	58.43	71.85	81.33	90.01	105.81
Se-NDNS years 12–15	99.13	23.77	64.75	83.70	95.54	112.12	142.92
Sex							
Males							
Se-NDNS years 1–11	81.50	14.84	58.04	72.01	81.33	90.01	105.02
Se-NDNS years 12–15	99.90	23.71	63.96	83.70	97.52	113.70	142.92
Females							
Se-NDNS years 1–11	81.46	15.39	58.43	71.85	80.54	90.01	106.60
Se-NDNS years 12–15	98.41	23.84	67.12	83.70	93.17	109.75	142.13
Age categories							
Age < 65 years							
Se-NDNS years 1–11	82.10	14.68	60.01	72.64	82.04	90.80	106.60
Se-NDNS years 12–15	99.35	23.62	67.12	83.70	94.75	112.91	142.92
Age ≥ 65 years							
Se-NDNS years 1–11	79.19	16.61	52.90	68.70	78.17	89.22	105.02
Se-NDNS years 12–15	98.64	24.17	62.38	82.91	96.33	110.54	142.92

entire range of exposure.

Analyses stratified by other characteristics showed substantially similar patterns with higher values in Se-EFSA compared to Se-NDNS, especially in years 12–15 (Supplementary Table S1). In addition, we found almost consistently higher estimates in years 1–11 compared to 12–15 in the Se-NDNS estimates. It was the opposite in Se-EFSA estimates in years 12–15 with generally higher values in the most recent survey compared to years 1–11.

Stratified analysis by sex and age categories showed a substantially similar pattern, with generally lower intakes in females (Table 3 and Supplementary Figures S2–S3) and partially in older (≥65 years) individuals (Table 3 and Supplementary Figures S4–S5) according to the Se-NDNS estimates, whilst in the Se-EFSA estimates differences were minimal/or lower magnitude in analyses stratified both by sex and age.

In the non-linear model comparing the Se intakes yielded by the two approaches (Fig. 3), we found a strong positive association for Se-NDNS intakes lower than 50 µg/day, while it was weaker at higher intake in years 1–11. In years 12–15 the association appeared to be weaker at lower intakes and much stronger at higher intake. In addition, the Se-EFSA estimates showed a higher variation compared to Se-NDNS values: the majority of subjects having Se-NDNS values in the range of 25–100 µg/day showed a greater spread of the corresponding Se-EFSA values in the range of 25–250 µg/day. The model also showed generally higher imprecision in years 12–15, characterized by a smaller number of subjects (i.e. 3786 and 627 in years 1–11 and 12–15, respectively). In both periods, a very high variation of Se-EFSA estimates can be seen compared to Se-NDNS, especially in years 12–15.

With reference to sex-stratified non-linear analysis comparing Se-EFSA to Se-NDNS estimates (Supplementary Figure S6), in years 1–11 the association was similar to the overall population, while in years

Table 3
Distribution of selenium intake (µg/day) estimated by the dietary questionnaire within the National Diet and Nutrition Survey (Se-NDNS) and by modelling intake from NDNS plasma selenium concentration based in the EFSA equation (Se-EFSA) in 1–11 and 12–15 years in overall population and divided by sex and age. SD: standard deviation (SD).

	Mean	SD	5th	25th	50th	75th	95th
All subjects							
Se-NDNS years 1–11	46.79	20.55	21.34	33.24	43.56	56.46	82.53
Se-NDNS years 12–15	43.47	14.29	22.07	34.42	42.35	51.76	70.03
Se-EFSA years 1–11	47.28	15.23	28.26	39.00	46.58	53.53	66.17
Se-EFSA years 12–15	69.19	36.28	33.32	48.48	57.95	74.94	146.55
Sex							
Males							
Se-NDNS years 1–11	52.58	23.00	24.45	37.91	49.03	62.65	90.12
Se-NDNS years 12–15	48.23	15.89	23.96	37.29	46.08	57.40	76.58
Se-EFSA years 1–11	47.16	14.18	27.95	39.13	46.58	53.53	65.53
Se-EFSA years 12–15	69.87	35.50	32.69	48.48	59.53	78.61	146.55
Females							
Se-NDNS years 1–11	42.47	17.30	20.07	30.54	39.81	51.70	72.55
Se-NDNS years 12–15	38.99	10.87	20.95	31.88	37.89	46.18	56.92
Se-EFSA years 1–11	47.37	15.97	28.26	39.00	45.95	53.53	66.80
Se-EFSA years 12–15	68.55	37.04	35.21	48.48	56.06	69.32	144.72
Age							
< 65 years							
Se-NDNS years 1–11	47.16	20.46	21.15	33.75	44.24	56.94	82.92
Se-NDNS years 12–15	44.47	15.08	22.01	34.85	43.43	52.82	72.60
Se-EFSA years 1–11	47.73	14.57	29.53	39.63	47.15	54.16	66.80
Se-EFSA years 12–15	69.51	36.39	35.21	48.48	57.32	76.77	146.55
≥ 65 years							
Se-NDNS years 1–11	45.42	20.83	21.68	31.61	41.54	53.59	79.90
Se-NDNS years 12–15	41.25	12.13	23.04	33.30	40.59	48.00	61.68
Se-EFSA years 1–11	45.63	17.38	23.84	36.48	44.06	52.90	65.53
Se-EFSA years 12–15	68.47	36.11	31.42	47.85	58.58	69.96	146.55

12–15 an almost linear relation was noted in males, while it was U-shaped in females. Similarly, in the age-stratified splines (Supplementary Figure S7), we found no substantial differences in years 1–11 between age groups, while the relation was linear in younger (<65 years) subjects and U-shaped and very imprecise in older (≥65 years) subjects. In both sex- and age-stratified analysis, we noted a very high imprecision and wider distribution of intakes from Se-EFSA compared to Se-NDNS, with values up to 250 µg/day in Se-EFSA and generally lower than 100 µg/day in Se-NDNS. This variation is particularly evident in years 12–15.

4. Discussion

In humans, the trace element Se is essential for a wide range of biochemical functions mediated by 25 human selenoproteins, in particular the glutathione peroxidases (GPx) which contain selenocysteine at the active site. Many authoritative bodies have used plasma GPx activity, as an indicator of dietary requirement, for deriving dietary

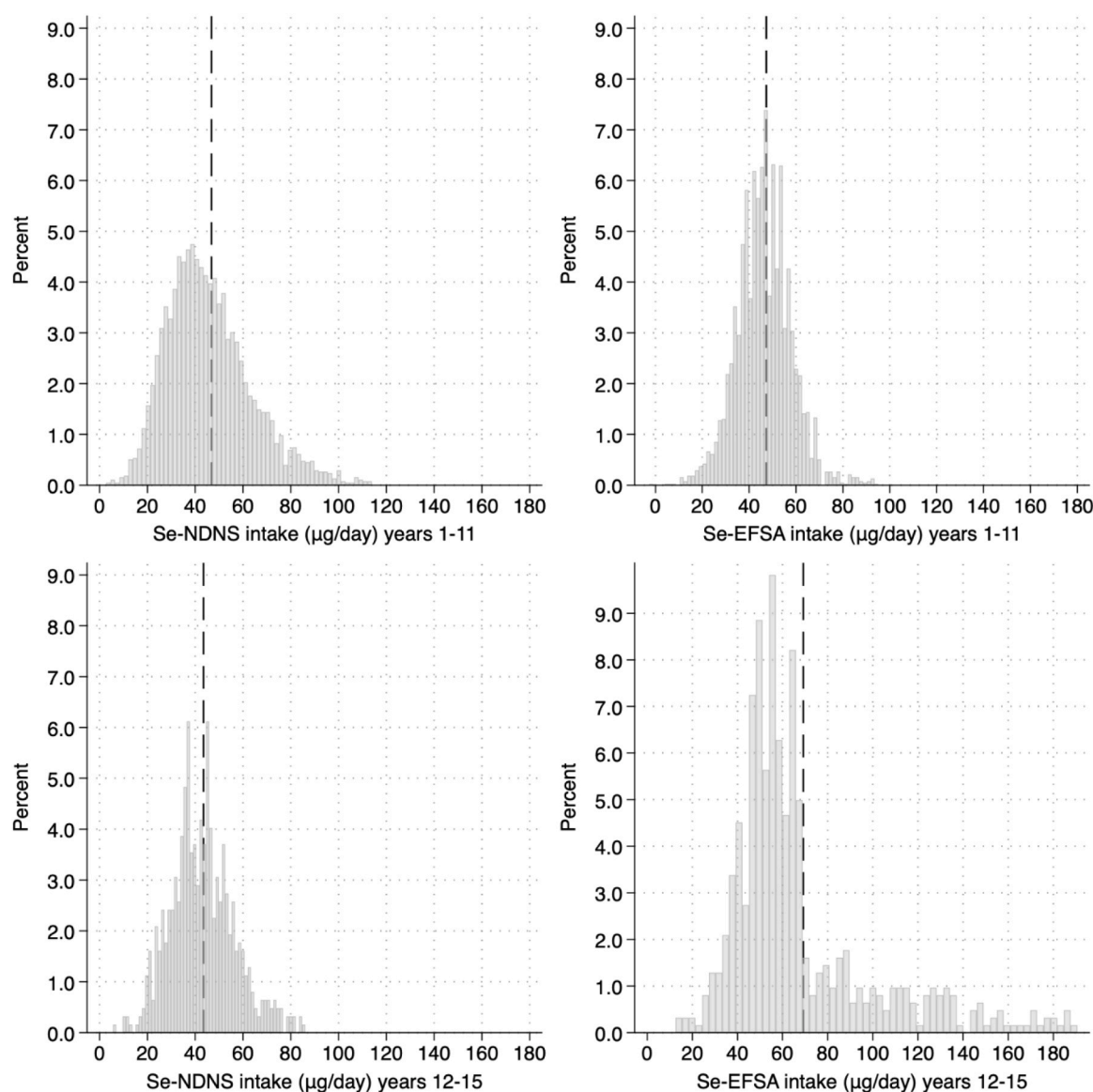


Fig. 2. Distribution of the estimated intakes ($\mu\text{g/day}$) based on selenium (Se) estimated using National Diet and Nutrition Survey questionnaire (Se-NDNS) and modelling plasma concentrations using EFSA equations (Se-EFSA) in overall population and divided by survey period (years 1–11 and 12–15). Vertical dash line indicates the mean value. Details of distribution of Se intakes are reported in [Table 3](#).

reference values (DRVs) for Se for adults [24,35,36]. However, more recently a plateau in the concentration of plasma selenoprotein P (SEPP1), the circulating blood transporter for Se in that contains the majority of Se in the body, has been proposed as an indicator of an adequate supply of Se to all tissues, and saturation of this functional Se body pool is assumed to ensure that the body's Se requirements are met in full [37,38]. There is widespread discrepancy in the DRVs for Se ([Table 4](#)) [24,35–46]. For example, in adult males the Reference Nutrient Intake (RNI), the quantity that meets the requirements of 97.5% of the population, set by WHO/FAO is 34 $\mu\text{g/day}$ [35] whereas the UK Department of Health (DH) has a value of 75 $\mu\text{g/day}$, considered necessary to reach a plateau in plasma GPx activity [24]. Although intakes of Se required to optimise SEPP1 concentration are higher than those required to maximise GPx activity, the difference between the RNI's set by WHO/FAO and UK-DH cannot be explained by the selection of different endpoints because they both used GPx activity. The UK COMA [24] noted that although no adverse consequences arise from blood levels of GPx activity which are below saturation, the RNI was derived as the level associated with functional saturation of GPx activity,

namely an intake of 1 $\mu\text{g/kg}$ body weight per day. WHO/FAO estimated that concentrations of plasma Se $> 80 \mu\text{mol/L}$ together with two-thirds of plasma saturation activity of GPx would be attained through a Se intake of 27 $\mu\text{g/day}$ by 65 kg adult male, and this was taken to be the average requirement (AR), which is the quantity of Se that meets the needs of 50% of the population. Assuming a standard deviation of 12.5% (to allow for individual variability) the RNI was then set at 34 $\mu\text{g/day}$ for males (and 26 $\mu\text{g/day}$ for females) aged 18–65 years.

In the 2014 scientific opinion on Se published by EFSA, the Panel concluded that there is insufficient evidence to derive an AI (and hence calculate the Recommended Nutrient Intake-RNI) [37]. They noted that a habitual Se intake of 50–60 $\mu\text{g/day}$ was not considered to be sufficient for SEPP1 concentration to reach a plateau in Finnish individuals [47], whilst a Se intake of 100 $\mu\text{g/day}$ and above was consistently associated with a plateau in plasma SEPP1 concentration in population groups from Finland, the UK and the USA. The relation between Se intake and levelling off of plasma SEPP1 concentration was used to derive an Adequate Intake (AI) of 70 $\mu\text{g/day}$ for adult males and females. The AI is based on observed or experimentally determined approximations of

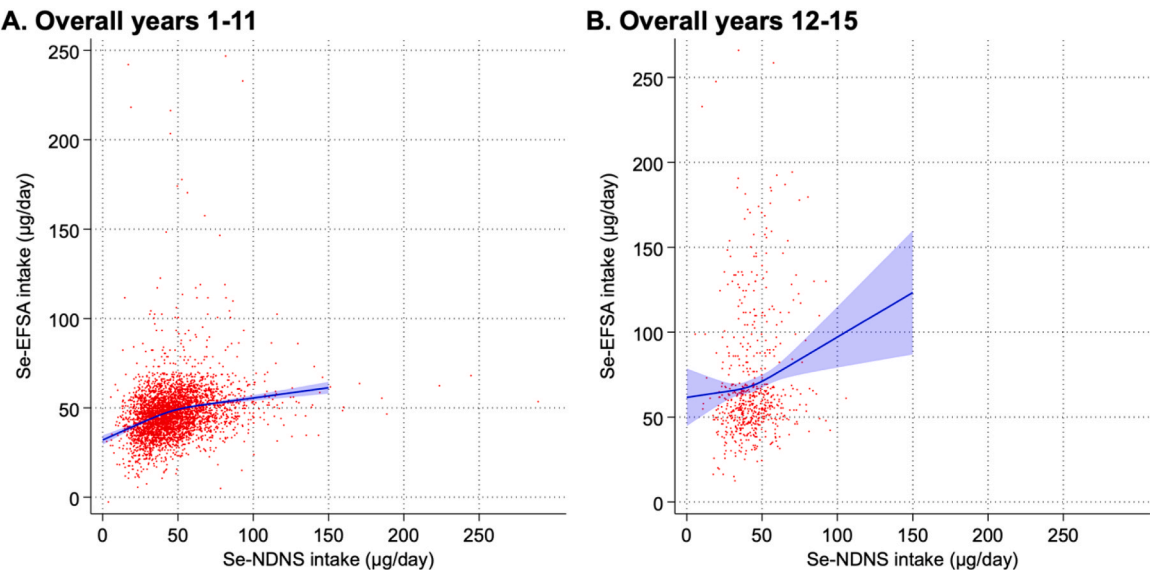


Fig. 3. Spline comparison of the estimated intakes (µg/day) based on selenium (Se) estimated using National Diet and Nutrition Survey questionnaire (Se-NDNS) with modelled plasma concentrations using EFSA equations (Se-EFSA) in overall population and divided by survey period (years 1–11 and 12–15). The blue solid line indicates the point estimate and the light blue shaded area represents the 95% confidence interval. Red dots represent individual observations.

Table 4
Dietary selenium recommendations (µg/day) for adult males and females from different countries and authorities.

Authority, year	RDA/RNI/LRNI (M/F)	AR/EAR (M/F)	AI (M/F)
SINU Italy, 2025 [39]			55/55
China, 2023 [40]	60/60	50/50	
Nordic, 2023 [38]		70/60	90/75
ANSES France, 2021 [41]			70/70
Japan, 2020 [42]	30/25	25/20	
AESAN Spain, 2019 [43]	70/55		
The Netherlands, 2018 [44]			70/70
D-A-CH, 2015 [45]			70/60
EFSA, 2014 [37]			70/70
Australia/NZ, 2006 [46]	70/60	60/50	
WHO/FAO, 2004 [35]	34/26	27/20	
IOM, 2000 [36]	55/55	45/45	
UK DH, 1991 [24]	75/60		

nutrient intake by a group (or groups) of healthy people, in the absence of signs of Se deficiency, and is almost certainly a higher value than the RNI because it is a value designed to cover the needs of every individual i.e. 100% of the population. The Nordic Nutrition Recommendations 2023 followed the same approach as EFSA in that they use the concentration of SEPP1 as the critical endpoint [38]; they noted that this is maximised at a Se concentration in plasma of about 110 µg/L or an intake of about 1.2 µg/kg bw, and set an AI of 90 µg/day for males and 75 µg/day for females.

The high variability in DRVs for Se reflects the lack of agreement on the best biomarker for assessing requirements and the consequent uncertainty about physiological requirements for optimal health [7,13]. It also indicates the limitations in using only biochemical indicators to define DRVs, while health-based indicators from epidemiologic studies linking Se exposure to health endpoints are recommended to assess its adequate intake [7]

In their 2013 Position Statement on Selenium and Health, SACN concluded that current UK Se intakes are generally below the RNI but found that no convincing demonstration of adverse health consequences of dietary intakes at the levels typically seen in the UK or benefits of higher intakes [25]. Similarly, in 2014, EFSA reinforced the need for further research to better characterise the relation between Se

intake/status, in particular when it is assessed using SEPP1 concentration, and health endpoints [37]. They commented that data from observational studies should be interpreted with caution, and although a negative association between plasma/serum Se concentration and the risk of certain types of cancer has been observed [48–51], a protective effect of Se supplementation ≥ 100 µg/day has not been demonstrated on cancer and other diseases [52–56], and even adverse effects on type 2 diabetes and lipid profile have been reported [4,57,58].

Our findings reassess and update dietary Se intake in the UK population: in the overall population, Se intakes from NDNS years 1–11 from the two methods are very similar (46.79 and 47.28 µg/day, respectively), while in NDNS years 12–15 showed substantially higher intake using the EFSA model (43.47 and 69.19 µg/day, respectively). In both periods and scenarios, our results indicate levels well above the WHO/FAO RNI of 34/26 µg/day for males and females [35], although considerably lower than the UK RNI of 75/60 µg/day [24] for NDNS years 1–11, and only partially lower for NDNS years 12–15. To answer the first study question due to the possibility that dietary intakes may have been under-reported (in line with the well-described energy under-reporting obtained using doubly-labelled water [59]) we computed intakes from plasma Se concentrations using the EFSA model and compared with intakes obtained from the NDNS dietary questionnaire. We observed some discrepancies between the two methods, in particular a possible underestimation of the overall exposure when relying only on dietary data. However, the differences in the associations depending on the study period also suggest that the EFSA modelling may be not entirely adequate to assess overall Se exposure, with the need to further elaborate the equations including correction factors for confounding factors such as sex and age. In fact, in years 1–11, we found a much weaker association between EFSA and NDNS estimates, which could be explained by an overestimation of the NDNS dietary intake (which is unlikely) or by an underestimate using the EFSA model, as this is characterized by a lower slope at higher plasma levels. However, the opposite finding in years 12–15, with stronger association at higher (>50 µg/day) NDNS intakes, do not allow us to assess which method is more accurate for estimating Se exposure. It should be noted that the EFSA model was primarily developed for population level risk assessment rather than for estimating individual Se intakes, thus explaining the high variability and imprecision of the estimates, especially above 110 µg/L where the uncertainty of the model is much higher as

demonstrated in [Supplementary Figure S1](#). These limitations suggest caution in the interpretation of the discrepancies between the two methods.

With regard to biomarkers of Se status that can be used to derive DRVs, plasma Se concentrations from 70 to 100 µg/L (0.9–1.3 µmol/L) have been proposed by different authors to reflect “selenium adequacy” [60]. In a review of the effect of Se supplementation on GPx activity in healthy subjects [61], no detectable increase in plasma GPx activity was observed in response to Se supplementation in subjects with a plasma concentration of 70 µg/L at baseline [62,63], suggesting that 70 µg/L could be taken as the threshold value. Data on usual SEPP1 concentrations in population groups are scarce but, unlike plasma Se concentration, it appears to represent a saturable pool of Se. No increment in plasma SEPP1 concentration was observed in subjects with an average habitual Se intake of around 100 µg/day [47], and in supplementation studies, maximal SEPP1 concentration is associated with plasma Se concentrations in the range of 90–140 µg/L (reviewed by Hurst et al., 2013 [64]), indicating that this is not an ideal biomarker for deriving DRVs. In addition, other pro-oxidant stressors, including Se itself, may upregulate selenoproteins and increase selenoprotein levels, further limiting their use to derive Se DRVs [7].

Comparison between the two periods of data collection for the NDNS is limited by changes in methodology (dietary intake assessment methods and blood collection and analysis). However, the latest values for plasma Se concentration ([Table 2](#)) indicate that the values are within the adequate range (as described above), with an overall mean of 99.13 µg/L and 5th centile 64.75 µg/L. On the other hand, Se intakes do not appear to be adequate when compared with the UK RNI values, either using estimates from the NDNS dietary intake data or to a lesser extent computed from plasma Se concentrations from the EFSA model, possibly suggesting that the RNI is too high. There is a clearly need to update the UK DRVs for Se in order to draw conclusions about the adequacy of the diet in the UK. It would also be very useful to further examine the relation between plasma Se and dietary intake because using a biomarker instead of dietary data provides information on longer-term exposure to Se and also avoids the inaccuracies associated with dietary intake methodology.

This study has several limitations. The main limitations anticipated relate to uncertainties in comparing NDNS years 1–11 and 12–15 due to some changes in dietary assessment methods as well as blood collection and analytical procedures. Second, the substantial variability and imprecision in Se intakes derived from plasma concentrations using the EFSA model warrant caution in the interpretation of such results, particularly because the model was developed primarily for population-level risk assessment rather than individual Se intakes and showed higher imprecision in the second part of the slope, above 110 µg/L. This limitation is particularly relevant for years 12–15, which included a substantial smaller number of participants than the earlier survey period. In addition, the EFSA model was derived from a dose-response relation using data from 63 pairs of mean values from 39 studies carried out in populations likely differing from UK population, at least for ethnicity and most likely also for sources of Se intake, and baseline Se. The lack of adjustment in such EFSA model for potential confounding factors could have influenced the relation between plasma and dietary Se intake, introducing additional uncertainty into the plasma-derived estimates. Finally, exclusion of individuals consuming Se supplements (>5 µg/day), because the chemical form of supplemented Se may not be adequately captured by the EFSA model, may limit the generalisability of our findings to the entire UK general population.

Abbreviations

AI: Adequate Intake
AR: Average requirement
COMA: Committee on Medical Aspects of Food and Nutrition Policy
DRV: Dietary Reference Value

EFSA: European Food Safety Authority
GPx: Glutathione peroxidase
LRNI: Lower Reference Nutrient Intake
NDNS: National Diet and Nutrition Survey
RNI: Recommended Nutrient Intake
SACN: Scientific Advisory Committee on Nutrition
Se: Selenium
SEPP1: Plasma selenoprotein P
WHO/FAO: World Health Organization/Food and Agriculture Organization

Authors' statement

S.F.-T. conceived the study; T.F. extracted data with the supervision of S.F.-T., performed the statistical analysis, interpreted the data with substantial contribution of S.F.-T. and M.V.; all authors prepared the first draft manuscript; all authors read and approved the final manuscript.

CRediT authorship contribution statement

Susan Fairweather-Tait: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Marco Vinceti:** Writing – review & editing, Writing – original draft, Supervision, Investigation. **Tommaso Filippini:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis.

Ethics declaration

Written informed consent to take part in the study and to publish the article has been obtained from all participants or their legal representatives. The privacy rights of participants have been observed.

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place. This study was approved by the Oxfordshire A Research Ethics Committee (Approval Ref. No. 07/H0604/113) and by the Cambridge South NRES Committee (Approval Ref. No. 13/EE/0016).

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Susan Fairweather-Tait is a member of SACN and represents SACN on the Project Board of the NDNS. The views expressed represent those of Susan Fairweather-Tait and not those of SACN, the NDNS Board or DHSC. Given their roles of Associate Editor, Tommaso Filippini, and of Editorial Board member, Marco Vinceti had no involvement in the peer-review of this article and have no access to information regarding its peer-review. Full responsibility for the editorial process was delegated to another journal editor. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jtemb.2026.127962](https://doi.org/10.1016/j.jtemb.2026.127962).

Data availability

Data described in the manuscript, code book and analytic code will be made available upon request pending an application and the approval of the corresponding author.

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