Appendix X Misreporting in the National Diet and Nutrition Survey 2019 to 2023: summary of results and their interpretation

X.1 Introduction

This appendix presents an overview of methods and results from the doubly labelled water (DLW) sub-study of the National Diet and Nutrition Survey (NDNS) carried out during years 12 to 14 (2019 to 2022) along with a summary of considerations relevant to the interpretation of these results.

If a healthy adult participant is in energy balance their habitual energy intake (EI) equals their habitual total energy expenditure (TEE). The DLW method is an established method widely agreed to be the most accurate way of measuring TEE in free-living individuals over one to 2 weeks and hence providing the ability to assess misreporting of EI (Barrie and Coward, 1985; Bluck, 2008). Even though growing children, and adults losing or gaining weight intentionally or unintentionally, are by definition, not in energy balance, the DLW method can still be used to assess TEE in such individuals.

When growth rates are not extremely rapid, for example in older children, correcting for weight change during DLW measurement has been found to make only a very small difference to calculated CO_2 production rate (and therefore TEE) (IDECG Working Group, 1990).

The methodology is objective and robust and demands relatively little from the participant. The method uses an oral dose of DLW, that is, water enriched in two naturally occurring stable isotopes, hydrogen (^2H, deuterium) and oxygen (^{18}O). By following the excretion of these isotopes from the body, through analysis of samples of body water (typically urine) over the subsequent 7 to 14 days, a mean daily rate of CO_2 production is obtained for the participant. From this average a daily TEE can be calculated which comprises the energy expended on basal metabolism, digestion and metabolism of food, and on physical activity. In brief, the method works as follows: the ingested DLW equilibrates with the total body pool of water, from which the rate of disappearance (r) of ^2H from the body represents water (^2H_2O) lost, for example in urine, breath, sweat, and breast milk. The rate of disappearance of oxygen-18 (^{18}O) represents the sum of both water ($H_2{}^{18}O$) loss and carbon dioxide ($C^{18}O_2$) loss in breath. Rapid exchange and equilibrium of ^{18}O between water, and carbon dioxide in body fluids, occurs via the action of the enzyme carbonic anhydrase in red blood cells and the lungs. The difference between these rates therefore equates to CO_2 production (that is $[rH_2O+rCO_2] - [rH_2O] = rCO_2$). TEE can be calculated from CO_2 production using standard respiratory equations because there is a known amount of heat (energy) associated with each litre of CO_2 produced during metabolism. The exact amount of CO_2 produced depends on the composition of the diet; that is the mixture of carbohydrate, fat, protein and alcohol consumed. It should be noted that the DLW method gives an integrated estimate of TEE for the period of measurement and not data for individual days.

A DLW sub-study has been an integral part of the UK NDNS since its inception and the NDNS is one of the few national large-scale population nutrition surveys to include this method. Since the start of the NDNS programme in 2008, a DLW sub-study has taken place once every 5 year contract phase to assess the degree of misreporting of EI estimated from reported food consumption. Previous sub-studies carried out in years 1 and 3 (2008 to 2009 and 2010 to 2011) and years 6 and 7 (2013 to 2014 and 2014 to 2015) compared TEE with EI from the 4-day paper diary. Appendix X of the NDNS years 1 to 4 report and appendix X of the UK years 1 to 9 report provide the results for these sub-studies.

With the change in dietary assessment method in year 12 of the NDNS from the paper diary to the online 24-hour recall tool, Intake24, the DLW sub-study in years 12 to 14 assesses for the first time the degree of misreporting of EI using Intake24.

X.2 DLW sub-study sample

In previous surveys, the aim was to obtain valid samples for approximately 10% of the core survey participants, aged 4 years and over, who completed a minimum of 3 of the four food diary days. For years 1 and 3 this was completed with the aim of obtaining valid samples for 20 participants per age and sex groups per year. As the degree of misreporting was observed to be greatest in the 16 to 49 years groups, the strategy was amended for Years 6 and 7 as follows: 4 to 10 years (n=60), 11 to 15 years (n=80), 16 to 49 years (n=100), 50 to 64 years (n=80) and 65 years and over (n=60) with equal numbers within group for each sex. In order to achieve the valid sample target, all age and sex groups were over-recruited with sample analysis occurring simultaneously where possible.

Due to the high cost of the DLW protocol and increasing budget pressures within the survey, the participant number targets for valid samples for years 12 to 14 were reduced compared to previous years to enable the sub-study to run within the available funding. A power calculation was undertaken to assess (i) the level of concordance (EI:TEE) that could be detected as statistically significant, and (ii) the degree of change in concordance possible to detect as statistically significant between the years 12 to 14 DLW sub-study and the NDNS DLW sub-studies in earlier years. This informed the sample size for achieved valid DLW samples for years 12 to 14 that were feasible within budget constraints. A sample size of 280 was selected as this enabled the DLW sub-study to detect a EI:TEE of 0.83 and a change in EI:TEE between Intake24 and the previous paper diary method of 0.14 within each age and sex group as statistically significant. Recruitment targets to achieve the required number of valid DLW samples were set as follows: 4 to 10 years (n=40), 11 to 15 years (n=60), 16 to 49 years (n=80), 50 to 64 years (n=60) and 65 years and over (n=40), with equal numbers within group for each sex.

In previous surveys, recruitment for the DLW sub-study was carried out approximately 2 to 3 weeks following the completion of the food diary. In years 1 and

3, the interviewer selected those participants they thought would fully complete the DLW protocol. In years 6 and 7, this changed such that participants were simply asked on a ‘first come first served’ basis, as long as their age and sex group cell had not been filled. For the present DLW sub-study, participants were recruited as in years 6 and 7; however, they were recruited following completion of the first dietary recall using Intake24 to increase overlap between the DLW measurement and dietary assessment.

Interviewers invited participants who had completed the first dietary recall; had height and weight measured and were not actively trying to lose or gain weight, to take part in the DLW protocol until the quota for each age and sex group was filled. In year 12 height and weight were measured at the interviewer visit. For years 13 and 14 when interviewing took place remotely due to COVID-19 protocols, height and weight were self-reported. However, it was stipulated that height and weight had to have been measured during the last month and not estimated.

Each age and sex group was slightly over-recruited to allow for drop out and unusable samples.

X.3 Overview of DLW methods in the NDNS

X.3.1 Isotope dosing and sampling

Each participant was asked to provide a baseline urine sample before receiving a weighed oral dose of $^{2}H_2{}^{18}O$ (Day 0). The dose was equivalent to 80 $mg \cdot kg^{-1}$ body mass deuterium oxide (D_2O, 99.9atom%, Cambridge Isotope Laboratories, Inc., MA, USA) and 150 $mg \cdot kg^{-1}$ body weight of $H_2{}^{18}O$ ($H_2{}^{18}O$, 10atom%, Taiyo Nippon Sanso Corporation, Tokyo, Japan).

Participants were asked to collect a single sample of their urine every day for a total of 10 days following the day of dosing and were asked not to collect samples from the first void of the day. The date and time of sample collection was noted by the participant in a log sheet. Urine samples were stored in 7ml glass bijou vials in the participants’ fridge, until the end of the 10-day collection. They were then collected by the interviewer and posted back to MRC Epidemiology Unit where they were frozen at -20°C pending analysis. Isotopic enrichments of the dose provided and of the urine samples were analysed using continuous flow isotope-ratio mass spectrometry (IRMS), described in section X.4.2.

X.3.2 Isotopic analyses

Measurements of deuterium enrichment of the samples were made using a Sercon ABCA-Hydra 20-22 instrument (Sercon Ltd, Crewe, Cheshire, UK).[1] This was done by equilibration of a 400 µL aliquot of urine with hydrogen gas over a platinum catalyst. A 500 µL aliquot of the sample and equilibration with 5% CO_2 (Roether 1970) was used to determine the oxygen isotopic composition of the urine samples. Analysis was completed using a Sercon ABCA continuous flow IRMS (Sercon Ltd, Crewe, Cheshire, UK). In all cases analytical standards prepared in house and traceable to the international standards Vienna Standard Mean Ocean Water (V-SMOW2) and Standard Light Arctic Precipitation (V-SLAP2) were included in each batch of samples analysed.

For the DLW sub-studies in years 1 and 3 and years 6 and 7, the isotope enrichment analysis took place at MRC Elsie Widdowson Laboratory (EWL; formerly MRC Human Nutrition Research). During 2018, the stable isotope facility at EWL was transferred to the Nutritional Biomarker Laboratory, MRC Epidemiology Unit, University of Cambridge. In order to ensure continuity of measurement in the NDNS and comparison of TEE measurements between survey years, a partial re-validation and cross validation of the stable isotope analysis methods was conducted. The aim of this work was to determine the precision and accuracy of the deuterium and ^{18}O analysis, and the reproducibility of the results with respect to previously measured NDNS year 6 (2013 to 2014) samples. Accuracy was demonstrated using international reference material, and re-analysis of samples demonstrated precision and consistency of analysis from earlier years. Further details on the experimental approach to the validation study and its results are available on request.

X.3.3 Energy expenditure calculations

TEE was calculated as described in the SACN dietary reference values for energy report (SACN, 2011) from slopes and intercepts of the isotope disappearance curves based on urine samples collected on days one to 10. Basal metabolic rate (BMR) for each individual was estimated using the Schofield equations (Schofield, 1985). Physical activity level (PAL) was expressed as TEE divided by BMR (Schofield 1985). This ratio removes virtually all the differences between individuals due to sex, age and body size.

X.3.4 DLW QC criteria

On receipt, all samples were checked for appropriate time and date information. Each participant sample set was required to include a pre-dose sample and a minimum of 6 post-dose samples to be included for analysis.

X.3.4.1 Analytical accuracy and precision:

[1] Deuterium analysis of Y12 urine samples was performed at Iso-Analytical Ltd, Crewe, UK using a Europa Scientific ANCA-GSL and 20-20 IRMS. Analysis of Years 13 and 14 samples was performed at the Nutritional Biochemistry Laboratory (NBL), MRC Epidemiology Unit, University of Cambridge, Cambridge, UK.

All samples were measured alongside 2 levels of secondary reference standards previously calibrated against the primary international standards Vienna-Standard Mean Ocean Water (vSMOW2) and Vienna-Standard Light Antarctic Precipitate (vSLAP2) (International Atomic Energy Agency, Vienna, Austria). Acceptable QC variation for deuterium is 5% and for 18-Oxygen 1%. All samples were measured in duplicate, with an acceptable difference of one ppm. Six discrete post-dose samples are required for modelling.

X.3.4.2 Modelling acceptance criteria:

Post modelling, valid data must meet the following 6 criteria defined in the SOP:

1. A pre-dose and 6 discrete post-dose samples analysed for both deuterium and 18-oxygen enrichment
2. R^2 of the isotope disappearance regression lines must be greater than 0.99.
3. Final sample enrichments are within 3 half-lives and for hydrogen the final sample enrichment must be higher than 128 ‰
4. Dilution space ratio lies between 1.00 and 1.07
5. Rate constant ratio lies between 1.1 and 1.7
6. The error of the model is less than 8%.

X.4 Results of DLW analysis in NDNS years 12 to 14 (2019 to 2022)

X.4.1 Participants

In total 344 eligible participants were recruited in the years 12 to 14 DLW sub-study.[2] Of these, 279 (82%) participants provided valid data for both TEE measured by DLW and EI estimated using data collected via Intake24 (see table X.1). The valid sample target was generally met in all groups except in males aged 50 to 64 years which was under target by 6, males and females aged 11 to 15 years which were under target by 1 and 3 respectively and females aged 65 years and over which was under target by 1 (see table X.1).

[2] For drop-out and unusable data numbers see the stage 2 evaluation report Appendix B3 participant flow chart

Table X.1 Number of valid DLW participants in NDNS years 12 to 14 (2019 to 2022)

Age group (years)	Sex	Target[3]	Year 12	Year 13	Year 14	Total
4 to 10	Male	20	15	4	1	20
4 to 10	Female	20	15	6	0	21
11 to 15	Male	30	7	15	7	29
11 to 15	Female	30	10	11	6	27
16 to 49	Male	40	14	21	8	43
16 to 49	Female	40	22	22	0	44
50 to 64	Male	30	11	10	3	24
50 to 64	Female	30	10	17	3	30
65 and over	Male	20	11	11	0	22
65 and over	Female	20	7	11	1	19
Total	Male	140	58	61	19	138
Total	Female	140	64	67	10	141

Of the 279 participants with valid data, 109 (39%) completed recalls and DLW concurrently, whilst the remaining 170 participants had a mean lag of 10 days (min = 0, max = 51) between recall 4 and DLW dosing day. Of the 170 non-concurrent participants, 24 completed recall 4 on the same day as DLW dosing took place. Of the 279 participants with valid data: 274 completed all 4 dietary recalls; 3 participants completed 3 recalls; and 2 participants completed two recalls.

[3] Target is valid sample target

For drop-out and unusable data numbers see the participant flow chart in appendix B3 of the stage 2 evaluation report.

Representativeness

Analyses have been carried out to assess the representativeness of the DLW sub-sample in relation to the achieved core survey sample in years 12 to 14. The following variables were assessed: BMI (kg per m^2), total EI (MJ per day), total fruit and vegetables consumption (g per day), free sugars intake (% of total energy) and saturated fatty acids intake (% of total energy). Figures X.1 to X.5 do not show any clear observed differences between the DLW sub-sample and the main survey sample responses, indicating that the DLW sub-sample is representative of the main NDNS sample with respect to these measures.

Figure X.1 Representativeness plot for BMI of valid DLW participants versus main NDNS participants in years 12 to 14 (2019 to 2022)

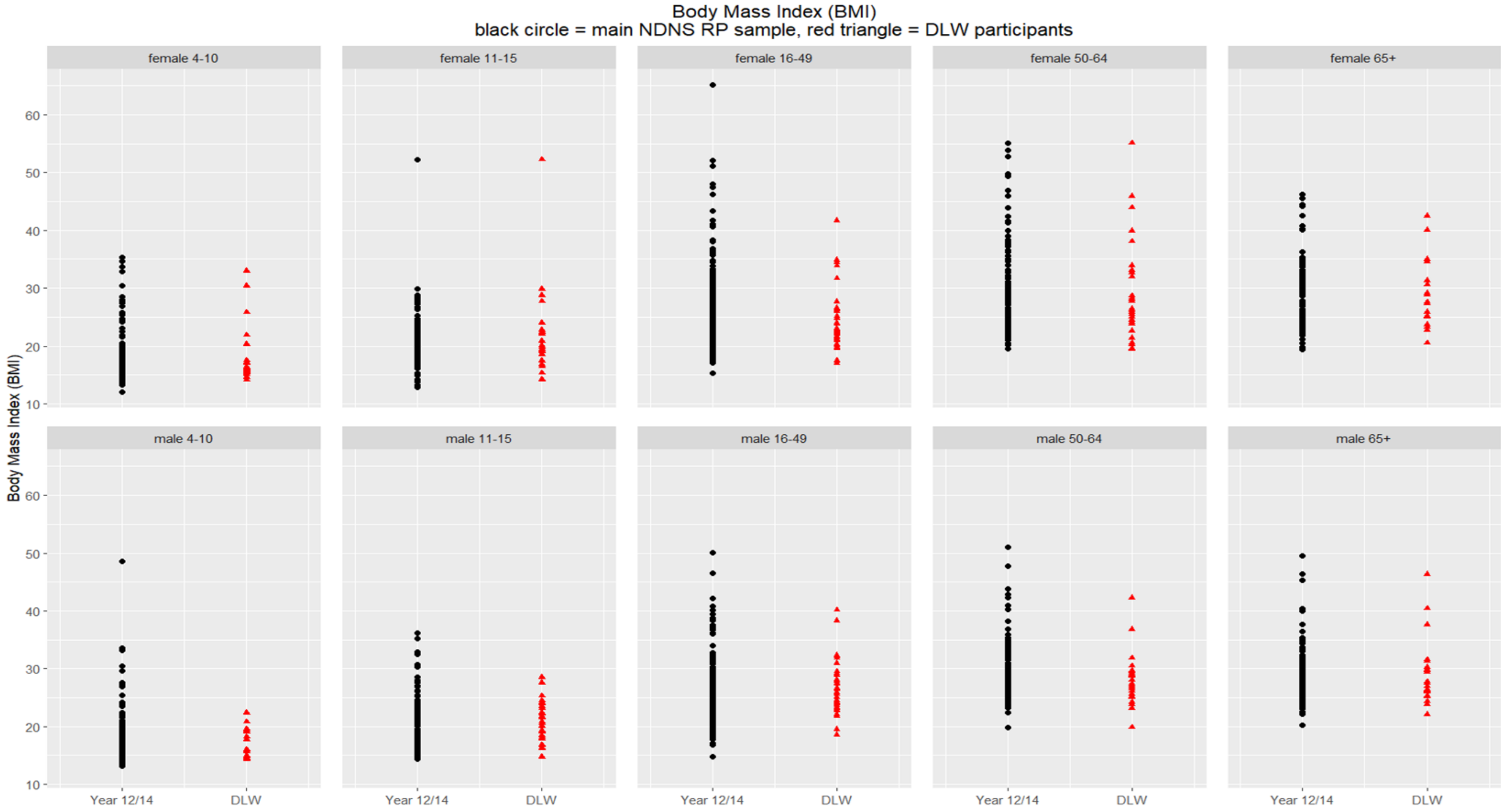


Figure X.2 Representativeness plot for total energy intake of valid DLW participants versus main NDNS participants in years 12 to 14 (2019 to 2022)

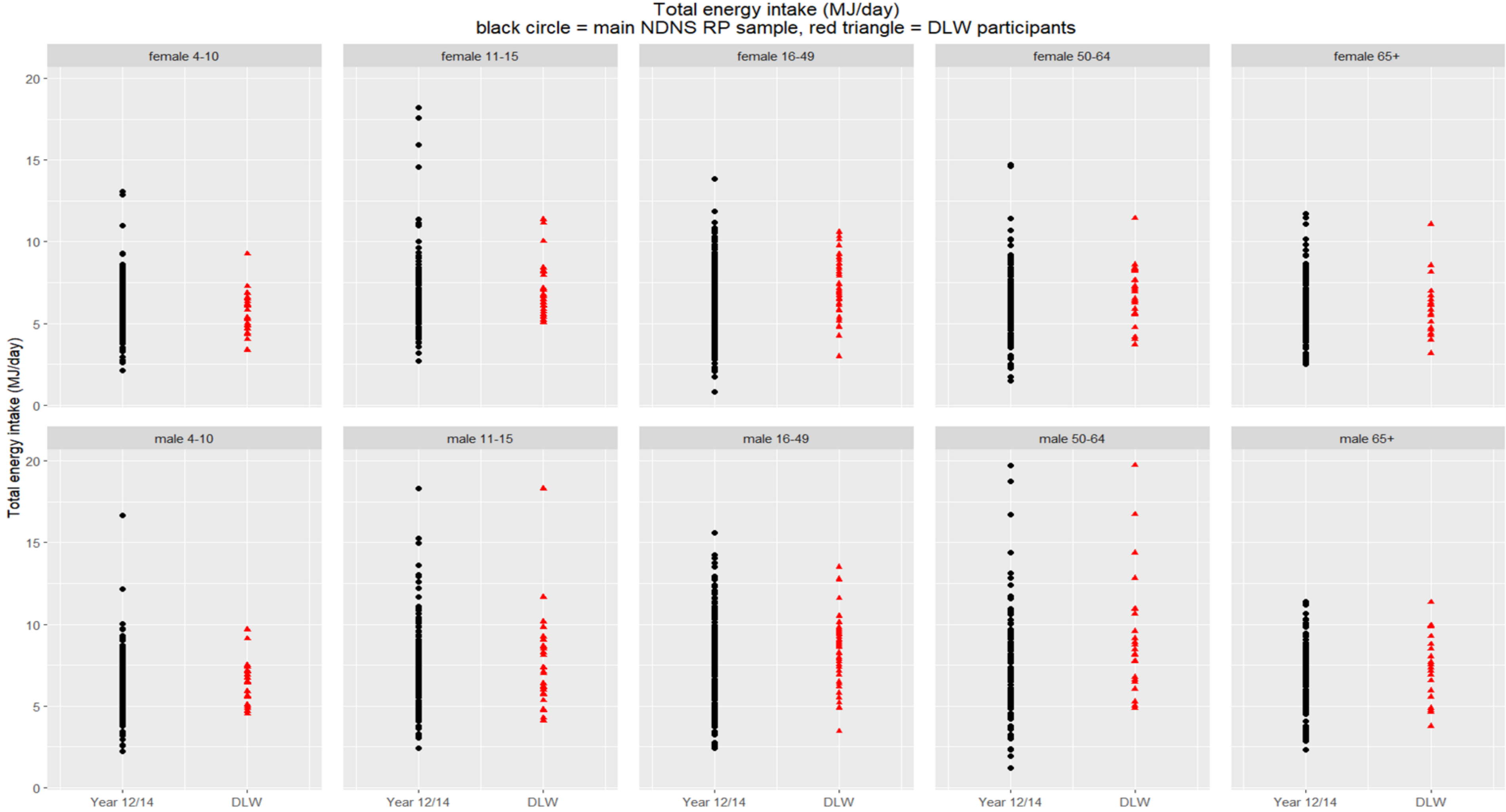


Figure X.3 Representativeness plot for total fruit and vegetables consumption of valid DLW participants versus main NDNS participants in years 12 to 14 (2019 to 2022)

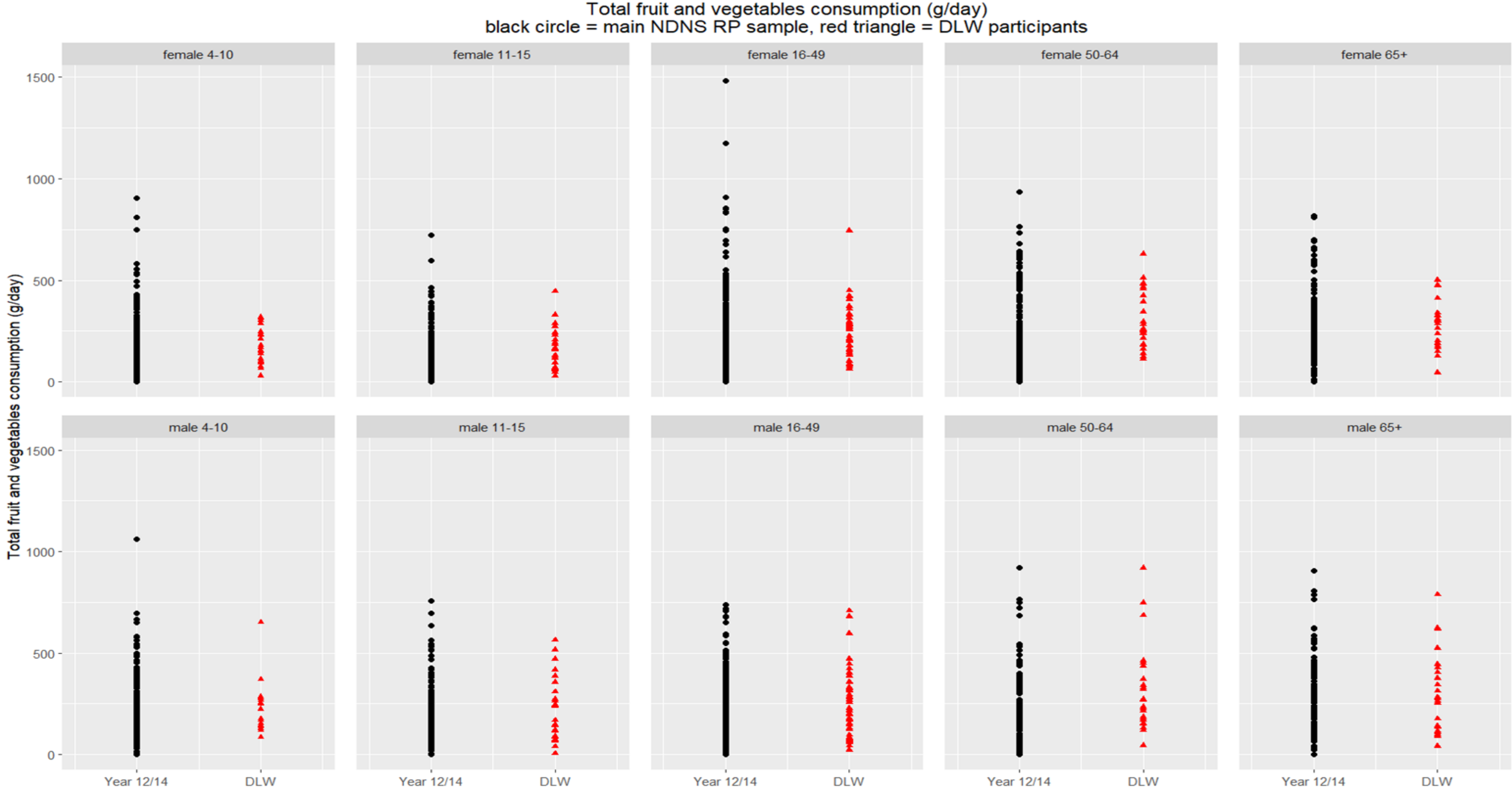


Figure X.4 Representativeness plot for free sugars intake of valid DLW participants versus main NDNS participants in years 12 to 14 (2019 to 2022)

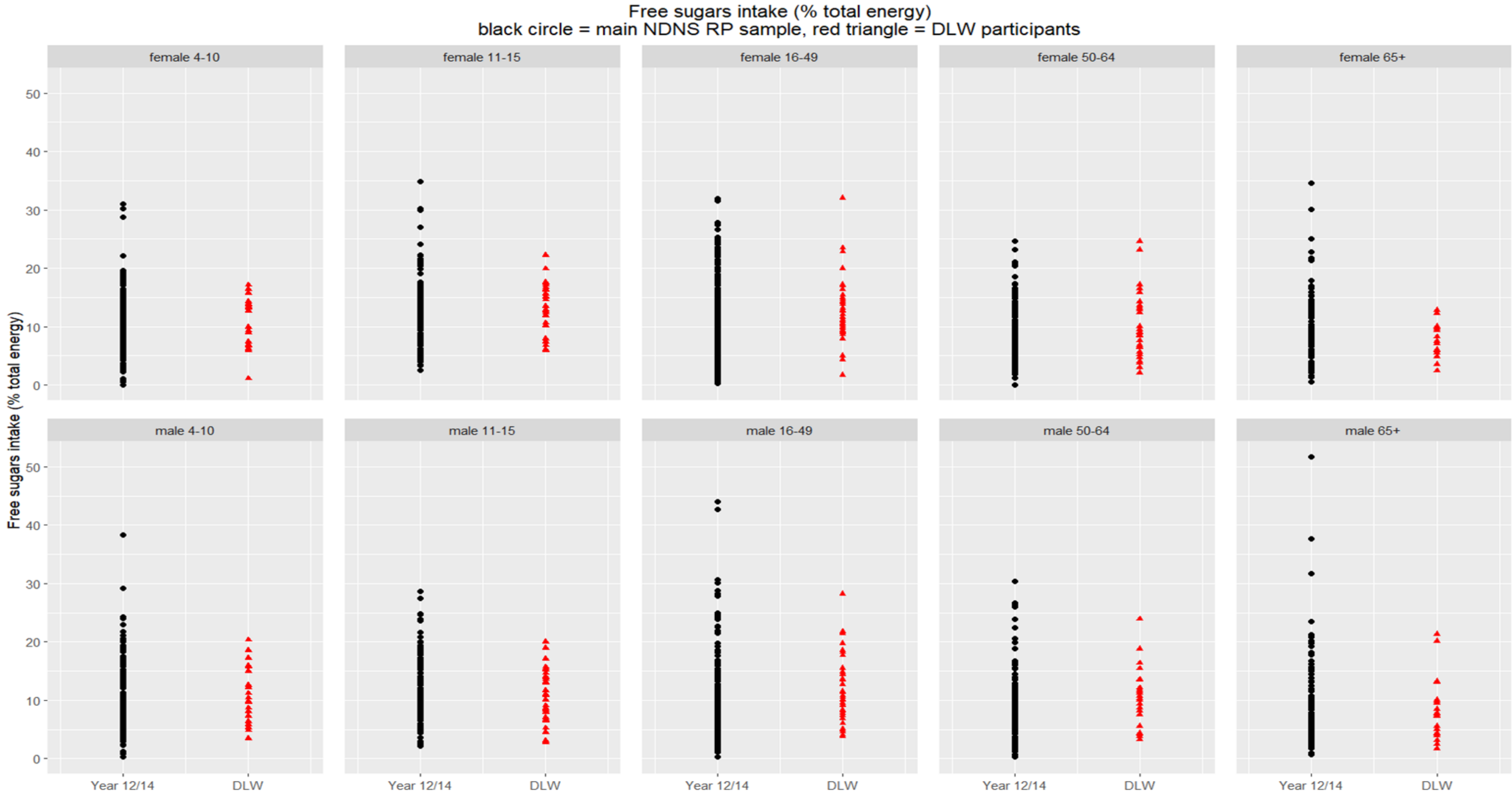
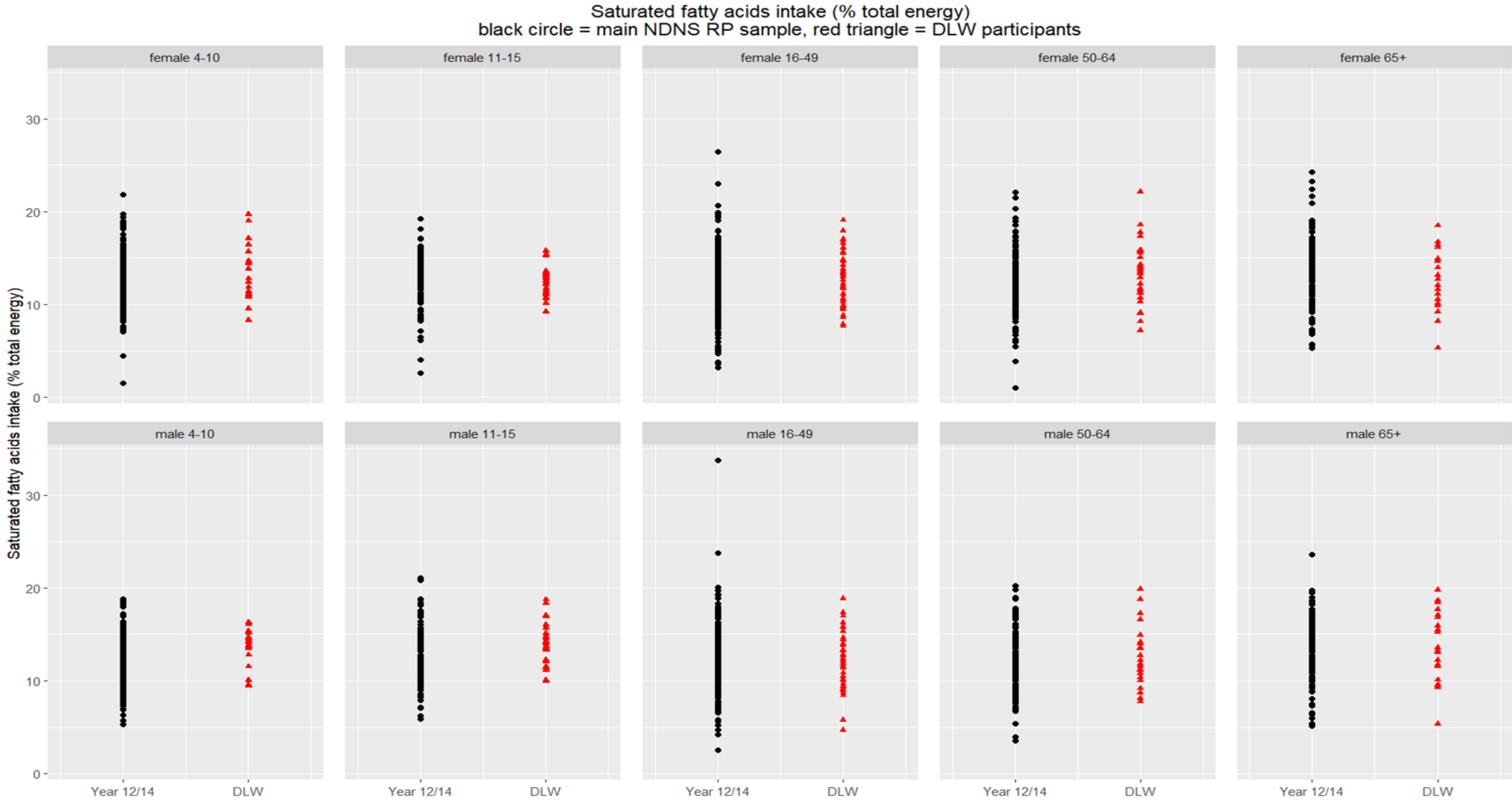


Figure X.5 Representativeness plot for saturated fatty acids intake of valid DLW participants versus main NDNS participants in years 12 to 14 (2019 to 2022)



X.4.2 Misreporting

Determination of adequacy of dietary reporting for a group of individuals is based on the ratio of reported EI and measured TEE. Because of the variability of EI and TEE, an individual may not be in perfect energy balance at any given time and EI:TEE will not equal 1.0. For some individuals their ratio at that time will be less than 1.0 and for some it will be greater than 1.0; but for a group, the expectation is that the mean ratio will be 1.0. Where the mean ratio for a particular group is lower than 1.0, this indicates a discrepancy between mean reported EI and estimated TEE, potentially due to underreporting of food intake or undereating during the dietary intake assessment period.

Tables X.2 and X.3 present the mean values for reported EI and estimated TEE along with the ratio (EI:TEE) and mean difference (TEE-EI) for the DLW sub-study carried out in years 12 to 14 (2019 to 2022).

The results of the analysis indicate good agreement between mean reported EI and mean estimated TEE in young children and less good agreement in older children and adults. Overall, in combined age and sex groups mean EI:TEE was 0.70. Mean EI:TEE was 0.63 for males and 0.67 for females aged 16 to 64 years (table X.2). Mean EI:TEE ranged from 0.60 for males aged 16 to 49 years at the lowest to 0.84 for boys aged 4 to 10 years at the highest (table X.3). For all age and sex groups mean EI:TEE was significantly different to 1.0 ($p<0.05$).

Table X.2 Mean values of reported EI and estimated TEE (kcal) in the DLW sub-study years 12 to 14 (2019 to 2022): combined age groups

Age group (years)	Sex	N	EI (kcal)	TEE (kcal)	TEE-EI	EI:TEE
4 and over	Males	138	1896	2903	1006	0.67
4 and over	Females	141	1592	2291	699	0.72
4 and over	Sex-combined	279	1743	2594	851	0.70
16 and over	Males	89	2003	3200	1197	0.63
16 and over	Females	93	1631	2442	812	0.68

16 and over	Sex-combined	182	1813	2813	1000	0.66
16 to 64	Males	67	2073	3348	1275	0.63
16 to 64	Females	74	1684	2540	856	0.67
16 to 64	Sex-combined	141	1869	2924	1055	0.65

Table X.3 Mean values of reported EI and estimated TEE (kcal) in the DLW sub-study years 12 to 14 (2019 to 2022)

Age group (years)	Sex	N	EI (kcal)	TEE (kcal)	TEE-EI	EI:TEE
4 to 10	Males	20	1518	1908	390	0.84
4 to 10	Females	21	1340	1682	341	0.82
4 to 10	Sex-combined	41	1427	1792	365	0.83
11 to 15	Males	29	1831	2677	845	0.69
11 to 15	Females	27	1655	2243	589	0.77
11 to 15	Sex-combined	56	1746	2468	722	0.73
16 to 49	Males	43	1995	3369	1373	0.60
16 to 49	Females	44	1710	2535	826	0.69

16 to 49	Sex-combined	87	1851	2947	1096	0.64
50 to 64	Males	24	2213	3312	1099	0.67
50 to 64	Females	30	1646	2547	901	0.65
50 to 64	Sex-combined	54	1898	2887	989	0.66
65 and over	Males	22	1787	2749	962	0.66
65 and over	Females	19	1425	2062	637	0.70
65 and over	Sex-combined	41	1619	2430	811	0.67

X.5 Discrepancy between mean values of reported energy intake and estimated energy expenditure in the NDNS

For combined age and sex groups within NDNS years 12 to14, underreporting of EI is approximately 30%. Previous NDNS DLW sub-studies, which used a paper-based diary method, have shown underreporting of EI of approximately 29%, very similar to that seen using Intake24. For further information and results regarding the comparison see the stage 2 evaluation report.

Misreporting in self-reported dietary methods is a well-documented issue (Archer, Hand and Blair, 2013). A number of different factors may contribute to why mean reported EI is lower than estimated TEE in the NDNS, including conscious or unconscious participant underreporting. Misreporting is difficult to address due to a variety of factors, including:

- memory, which is subject to recall bias
- social desirability bias, where people may consciously or sub-consciously over- or under- report some foods (for example those perceived as healthy or unhealthy)
- portion sizes, portion estimation can be difficult to report and its assessment can be affected by subjective and cognitive factors
- food composition assumptions

- dietary complexity and range, including for foods and meals with many ingredients, and where eaten in different settings

These factors have been discussed previously in the NDNS RP years 1 to 9 report.

A report by Thane and Stephen (2006*)* has shown that reported EI is higher on Saturdays and to some extent on Fridays and Sundays in some age groups. Since the measurement of TEE by DLW always covered at least one weekend day and the estimate of dietary EI in the NDNS did not necessarily include weekend days, the question may be raised as to whether this might explain some of the difference between reported EI and estimated TEE. For the DLW sub-study, 30% of participants did not report EI for Saturday or Sunday. This was because the aim within NDNS years 12 to 15 was to collect EI data across an even spread of days which, if all participants completed 4 recalls, would mean 26% would not have a recall for Saturday or Sunday. Therefore, day of the week may be a factor influencing the difference between EI and TEE.

A further factor affecting misreporting could be that EI and TEE data are not collected over the same time period. As has been reported here only 39% of the participants completed EI assessment and TEE measurements concurrently.

X.6 Application of the DLW method in the NDNS

Biases such as underreporting are inherent in self-reported dietary data but remain an area of ongoing concern and warranting further investigation. As TEE using DLW was only estimated in a sub-sample of the NDNS, self-reported energy intake has not been adjusted in this report.

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