Appendix X Misreporting in the National Diet and Nutrition Survey Rolling Programme (NDNS RP): summary of results and their interpretation

X.1 Introduction

In the NDNS RP Years 1 to 9 (2008/09 – 2016/17) estimates of energy intake (EI) from the estimated 4-day diary were compared with measurements of total energy expenditure (TEE) using the doubly labelled water (DLW) technique in 2 separate sub-samples of survey participants, as an objective biomarker to validate EI estimated from reported food consumption.

This appendix presents an overview of methods and results from the second DLW sub-study of the NDNS RP carried out during Years 6 and 7 (2013/14 – 2015/16), along with a summary of considerations relevant to the interpretation of these results. Appendix X of the UK Years 1 to 4 report[1] provides the results of the for the DLW sub-study carried out in Years 1 and 3 (2008/09 and 2010/11).

X.2 The DLW method and application in NDNS RP and previous surveys

The DLW method is an established method widely agreed to be the most accurate way of measuring energy expenditure (EE) in free-living individuals over 1 to 2 weeks, and hence detecting misreporting of EI.[2,3] The methodology is objective and robust and demands relatively little from the participant. The UK NDNS (past surveys and the current RP) is one of the few national large-scale population surveys to include this method. The method uses an oral dose of DLW, i.e. water enriched in two naturally occurring stable isotopes, hydrogen (^{2}H, 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 ^{2}H from the body represents water ($^{2}H_2O$) 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 (i.e. $[rH_2O+rCO_2] – [rH_2O] = rCO_2$). EE 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 EE for the period of measurement and not data for individual days.

In healthy adult participants, if, for a given period of time, energy consumed matches total energy expended, they are in energy balance. In this circumstance, TEE is equal to EI and measures of habitual TEE can therefore be used to assess the level of misreporting of energy intake in habitual reported dietary data.[2,3] 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.[a,4]

For the majority of NDNS carried out prior to the RP, TEE was measured in sub-studies prior to and in a separate sample from the main survey in order to validate the dietary method; hence there was no assessment of underreporting in the survey itself. For example the adult NDNS of 2000/01,[5] a DLW component was included in a feasibility study to compare reported EI from the 7-day weighed dietary intake with TEE measured concurrently. Data on EI and TEE from DLW were available for 64 individuals.[6]

Prior to the launch of the NDNS RP to determine which method to use in the survey, a Comparison Study was conducted in 2007[b] to compare two dietary methods: four 24-hour recalls and a 4-day estimated (unweighed) diary in 1,000 participants (500 for each method). As part of this comparison, TEE using DLW was measured in 160 survey participants, consisting of 80 individuals for each dietary method, subdivided into 5 reporting age groups: 4 to 10 years, 11 to 15 years, 16 to 49 years, 50 to 64 years and 65 years and over.[7] Following on from the Comparison Study, the NDNS RP adopted the 4-day estimated food diary and has included two further DLW sub-studies in Years 1 to 9 for measurement of TEE. In NDNS RP Years 1 to 4 (2008/09 – 2012/13), in the first study, TEE was measured in 371 participants (approximately 10% of the sample); recruitment took place in Years 1 and 3 with the aim of recruiting 20 participants per set age/sex groups per year. Further details of the protocol and results can be found in appendix X in the NDNS RP Years 1 to 4 (combined) report.[1]

In the second funding phase of the NDNS RP (Years 6 to 9; 2013/14 – 2016/17), recruitment for the DLW sub-study took place during Year 6 (2013/14) and the first part of Year 7 (2014/15). DLW was administered to a subgroup of survey participants, aged four years and over, spread between the same age/sex groups as for the first DLW sub-study (as reported in

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[a] When growth rates are not extremely rapid, e.g. 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).

[b] In the DLW component of the NDNS RP Comparison Study the target was to recruit 8 participants to each of the 10 age/sex groups, for each of the 2 dietary assessment methods being compared - repeat 24-hour recall and 4-day estimated diary (160 respondents or 16% of the intended total number of participants). Only the results for the diary respondents, the equivalent method to the main survey, are presented in the report appendix (n=78).

the NDNS RP Years 1 to 4 (combined) report).[1] However, as the observed level of misreporting in the earlier years was greatest in the 16 to 49 years age group, the recruitment design was amended for Years 6 and 7. The aim was to recruit approximately 10% of the core survey participants (i.e. those completing a food diary) for Years 6 to 9, and was 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.

The protocol was the same as that used in Years 1 and 3 of the NDNS RP[1]in that the DLW component took place after but within 1 month (typically 2 to 3 weeks) of the dietary assessment period, with the DLW participants recruited at the third interviewer visit, when the completed food diaries were collected. However, for Years 6 (2013/14) and 7 (2014/15) the recruitment strategy changed such that all participants were asked on a 'first come first served' basis to take part in the DLW sub-study, as long as their age/sex group cell had not been filled. This was different to the recruitment strategy in Years 1 and 3 where only those participants the interviewer believed to be more likely to agree and fully complete the DLW component were asked to take part. No adjustment was made during analysis to account for any potential differences arising from the new recruitment strategy.

The results of the analysis of the DLW sub study in NDNS RP Years 6 and 7 are presented below. This appendix presents a series of considerations and potential factors that may have influenced the degree of underreporting in the NDNS RP despite vigorous efforts to obtain complete dietary intake records.

X.3 Number of participants in the DLW sub-studies

The recruiting targets for DLW for Years 6 (2013/14) and 7 (2014/15) were 380 participants in total (approximately 10% of the core sample for NDNS RP Years 6-9). Interviewers invited participants who had completed a food diary to take part in the DLW protocol until the quota for each age/sex group was filled. Each age/sex group was slightly over-recruited (to allow for drop out and unusable samples) giving a total of 399 participants. Table X.1 shows that almost 98% of the survey participants were recruited in Year 6 with the remaining 2% recruited in Year 7.

Table X.1 Number of DLW recruits in Years 6 (2013/14) and 7 (2014/15)

Age group	Sex	Year 6	Year 7	Total
4-10 years	Male	32	1	33
	Female	31	1	32
11-15 years	Male	42	0	42
	Female	41	1	42
16-49 years	Male	48	3	51
	Female	50	1	51
50-64 years	Male	40	2	42
	Female	41	1	42
65+ years	Male	32	0	32
	Female	31	1	32
Total	Male	194	6	200
	Female	194	5	199

X.4 Overview of DLW methods in the NDNS RP

X.4.1 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·kg^{-1} body mass deuterium oxide and 150 mg·kg^{-1} of $H_2{}^{18}O$ (Sercon Ltd, 3b Crewe Trade Park, Gateway, Crewe, Cheshire, UK, CW1 6JT).

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 (Scientific Laboratory Supplies, Unit 26/27, Wilford Industrial Estate, Wilford, Nottingham NG11 7EP, UK), generally at +4°C in the participants' fridge, until the end of the 10-day collection. They were then collected by the interviewer and posted back to MRC Elsie Widdowson Laboratory, Cambridge (EWL)[c] where they were frozen at -20°C pending analysis. Isotopic enrichments of the dose provided and of the urine samples were analysed using isotope-ratio mass spectrometry (IRMS) at EWL, described in section X.4.2.

X.4.2 Isotopic analyses

Measurements of deuterium enrichment of the samples were made using a Sercon ABCA-Hydra 20-22 instrument (Sercon Ltd, 3b Crewe Trade Park, Gateway, Crewe, Cheshire, UK, CW1 6JT). This was done by equilibration of a 400µL aliquot of urine with hydrogen gas over a platinum catalyst. A 500µL aliquot of the sample and equilibration with CO_2[8] was used to determine the oxygen isotopic composition of the urine samples. Analysis was completed using an AP2003 continuous flow IRMS (Analytical Precision Ltd, Northwich, Cheshire, UK). In all cases analytical standards prepared in house and traceable to the international standards Vienna Standard Mean Ocean Water (V-SMOW) and Standard Light Arctic Precipitation (SLAP) were included in each batch of samples analysed.

X.4.3 Energy expenditure calculations

TEE was calculated as described in the SACN dietary reference values for energy report (2011)[9] from slopes and intercepts of the isotope disappearance curves based on urine samples collected on days 1 to 3 and days 8 to 10. Basal metabolic rate (BMR) for each individual was estimated using the Schofield equations.[10] Physical activity level (PAL) was expressed as TEE divided by BMR.[9] This ratio removes virtually all the differences between individuals due to sex, age and body size.

X.5 Results of DLW analysis in NDNS RP Years 6 (2013/14) and 7 (2014/15)

[c] Formerly MRC Human Nutrition Research (HNR).

As described earlier, if an individual is in energy balance their habitual EI equals their habitual TEE and their ratio of EI:TEE is 1.0. 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 EE, 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 measured EE, potentially due to underreporting of food intake or undereating during the dietary intake assessment.

Tables X.2 and X.3 present the mean values for reported EI and measured TEE along with the ratio of EI:TEE for the DLW sub-study carried out in Years 6 (2013/14) and 7 (2014/15). The results of the analysis indicate good agreement between mean reported EI and mean measured EE in children and less good agreement in adults (defined in this appendix as those aged 16 to 64 years). Overall, in combined age/sex groups mean EI:TEE was 0.71; mean EI:TEE was 0.67 for men and 0.66 for women aged 16 to 64 years (table X.3). Mean EI:TEE ranged from 0.64 for women aged 50 to 64 years at the lowest to 0.88 for girls aged 4 to 10 years at the highest. The levels of misreporting observed in Years 6 and 7 are similar to those observed in Years 1 (2008/09) and 3 (2010/11).[1] These findings are consistent with those of other studies using similar dietary assessment methods in free-living adults.

Table X.2 Mean values of reported EI and measured TEE (kcal) in the DLW sub-study (Years 6 (2013/14) and 7 (2014/15))

Age group	Sex	N	EI (kcal)	TEE (kcal)	TEE-EI	EI:TEE
4-10 years	Males	33	1565	1862	297	0.85
	Females	32	1426	1655	228	0.88
	Sex-combined	65	1497	1760	263	0.87
11-15 years	Males	42	1775	2705	930	0.68
	Females	42	1575	2307	732	0.70
	Sex-combined	84	1675	2506	831	0.69

16-49 years	Males	51	2052	3231	1179	0.65
	Females	51	1709	2606	898	0.68
	Sex-combined	102	1881	2919	1038	0.67
50-64 years	Males	42	2065	3074	1009	0.69
	Females	42	1577	2474	897	0.64
	Sex-combined	84	1821	2774	953	0.67
65+ years	Males	32	2000	2763	763	0.73
	Females	32	1541	2212	671	0.71
	Sex-combined	64	1770	2488	717	0.72

Table X.3 Mean values of reported EI and measured TEE (kcal) in the DLW sub-study (Years 6 (2013/14) and 7 (2014/15)) – combined age groups

Age group	Sex	N	EI (kcal)	TEE (kcal)	TEE-EI	EI:TEE
4 years and over	Males	200	1908	2787	879	0.71
	Females	199	1580	2299	718	0.71
	Sex-combined	399	1745	2543	799	0.71
16 years and over	Males	125	2043	3059	1015	0.68
	Females	125	1622	2461	839	0.68
	Sex-combined	250	1832	2760	927	0.68
16-64 years	Males	93	2058	3160	1102	0.67
	Females	93	1649	2546	897	0.66
	Sex-combined	186	1854	2853	1000	0.67

X.6 Discrepancy between mean values of reported energy intake and measured energy expenditure in the NDNS RP

Misreporting in self-reported dietary methods is a well-documented issue.[11] The NDNS RP (and previous NDNS) is one of the few national large-scale population surveys to use DLW as an objective biomarker to validate EI estimated from reported food and drink consumption. A number of different factors may contribute to why mean reported EI is lower than measured EE in the NDNS RP, including conscious or unconscious participant underreporting. A summary of other considerations is presented below.

a. Inclusion of the DLW sub-study in the NDNS RP protocol

Unlike previous NDNS, the RP and the preceding Comparison Study included a DLW sub-study within the main survey protocol; DLW was included within separate feasibility studies for previous NDNS. This may have implications for sampling, participant compliance and the extent of misreporting. Furthermore, to minimise participant burden, the DLW protocol for the NDNS RP was carried out after the diary recording of food and drink consumption, generally 2 to 3 weeks later, rather than concurrently as was the case in the separate sub-studies carried out in previous NDNS and more generally in other studies where TEE is measured using the DLW method.[12,13] Efforts were made in the NDNS RP (including for example, rigour of interviewer training, participant instruction, interviewer-participant mid-week checks) to encourage participants to fully record their usual intake and for the DLW participants to follow their usual dietary and activity patterns, but compliance with this cannot be assumed.

The difference in timing of dietary intake assessment and DLW measurement may have contributed to underreporting in the NDNS RP, with the known tendencies to underreport or under eat when actively recording dietary intake. The tendency to over report physical activity has also been observed when assessed by questionnaire and activity monitors.[14,15,16] However, compared to these subjective methods, the DLW method for measuring TEE is very much an objective measure.

b. Representativeness of the DLW sample in Years 1 (2008/09), 3 (2010/11), 6 (2013/14) and 7 (2014/15)

The DLW participants represent a small proportion of the main NDNS RP sample. Interviewers invited fully productive participants to take part in the DLW sub-study on a first come, first served basis until age/sex quotas were filled.

To assess the representativeness of the DLW sample in relation to the main survey sample (for years when the DLW sub-study was conducted) the following plots were created for 5 variables of interest: BMI (kg/m^2) (Figure X.1), TEI (MJ/day) (Figure X.2), total fruit and vegetables consumption (g/day) (Figure X.3), free sugars intake (% total energy) (Figure X.4) and saturated fatty acids intake (% food energy) (Figure X.5). Figures X.1-X.5 do not show any clear differences between the DLW sample and the main survey sample responses, indicating that the DLW sample is representative of the main NDNS RP sample with respect to these measures.

Figure X.1 Representativeness plot for BMI of DLW recruits versus main NDNS RP recruits in Years 1 (2008/09), 3 (2010/11) and 6 and 7 (combined) (2013/14-2014/15

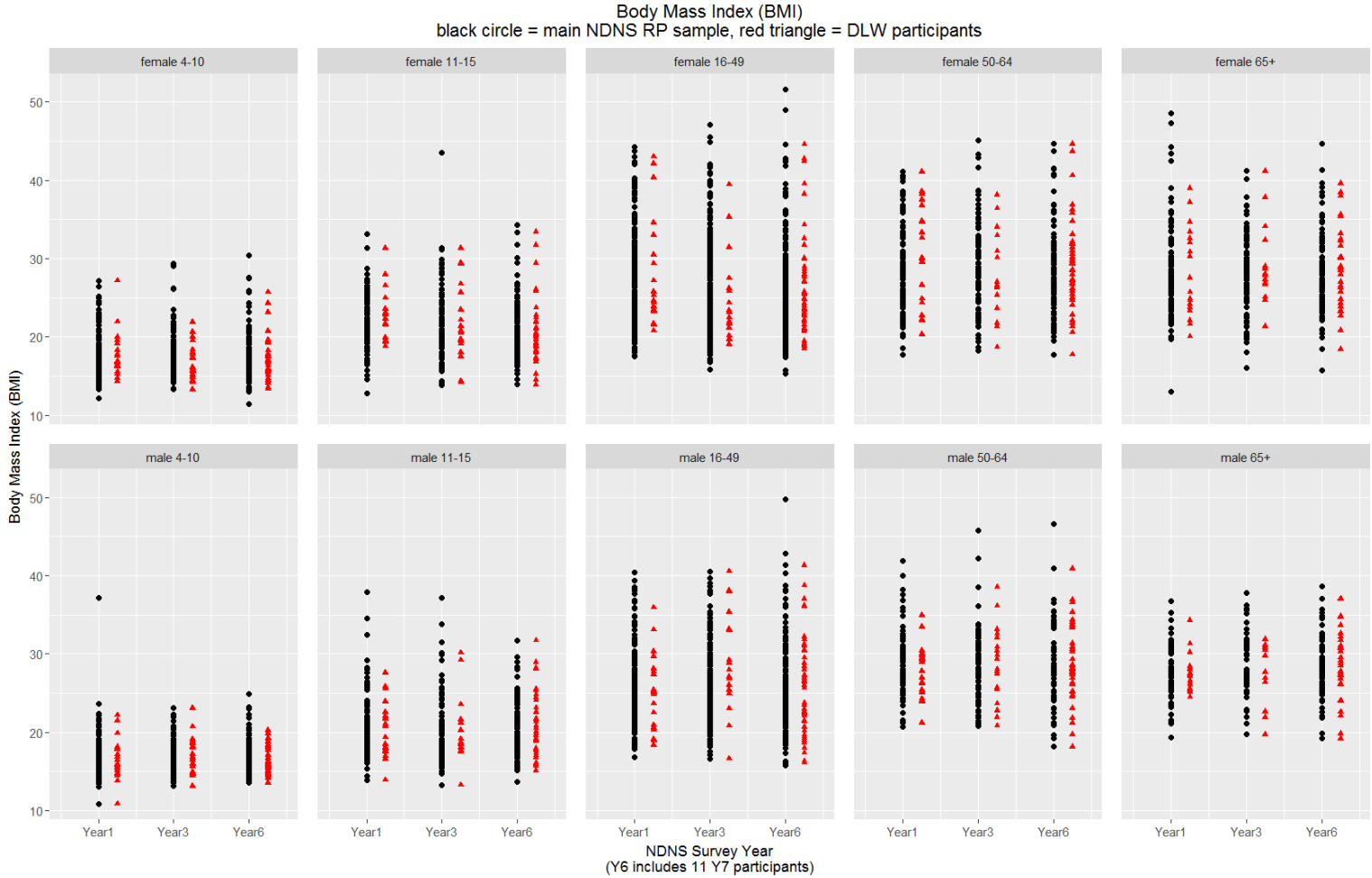


Figure X.2 Representativeness plot for total energy intake of DLW recruits versus main NDNS RP recruits in Years 1 (2008/09), 3 (2010/11) and 6 and 7 (combined) (2013/14-2014/15)

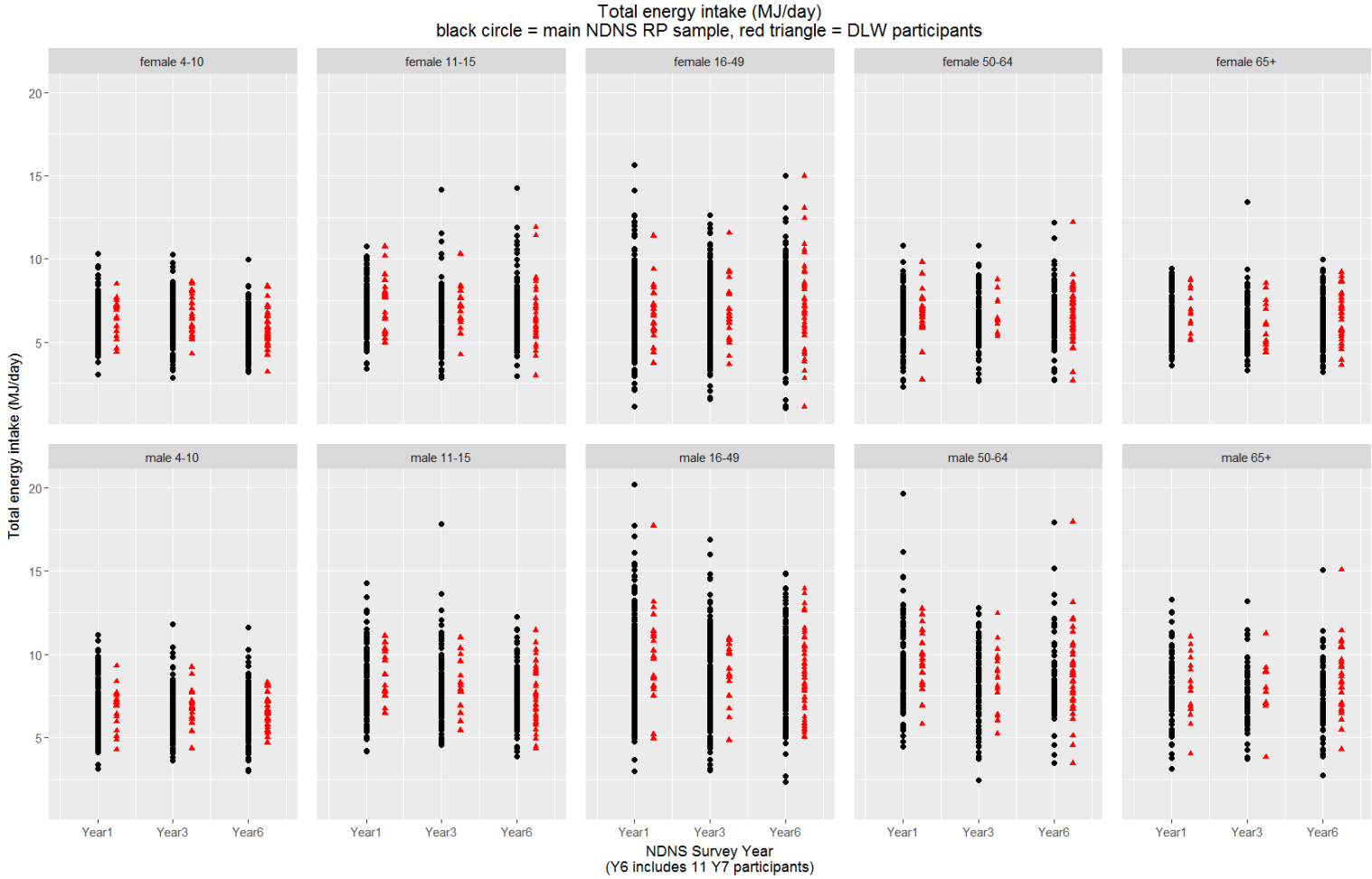


Figure X.3 Representativeness plot for total fruit and vegetables consumption of DLW recruits versus main NDNS RP recruits in Years 1 (2008/09), 3 (2010/11) and 6 and 7 (combined) (2013/14-2014/15)

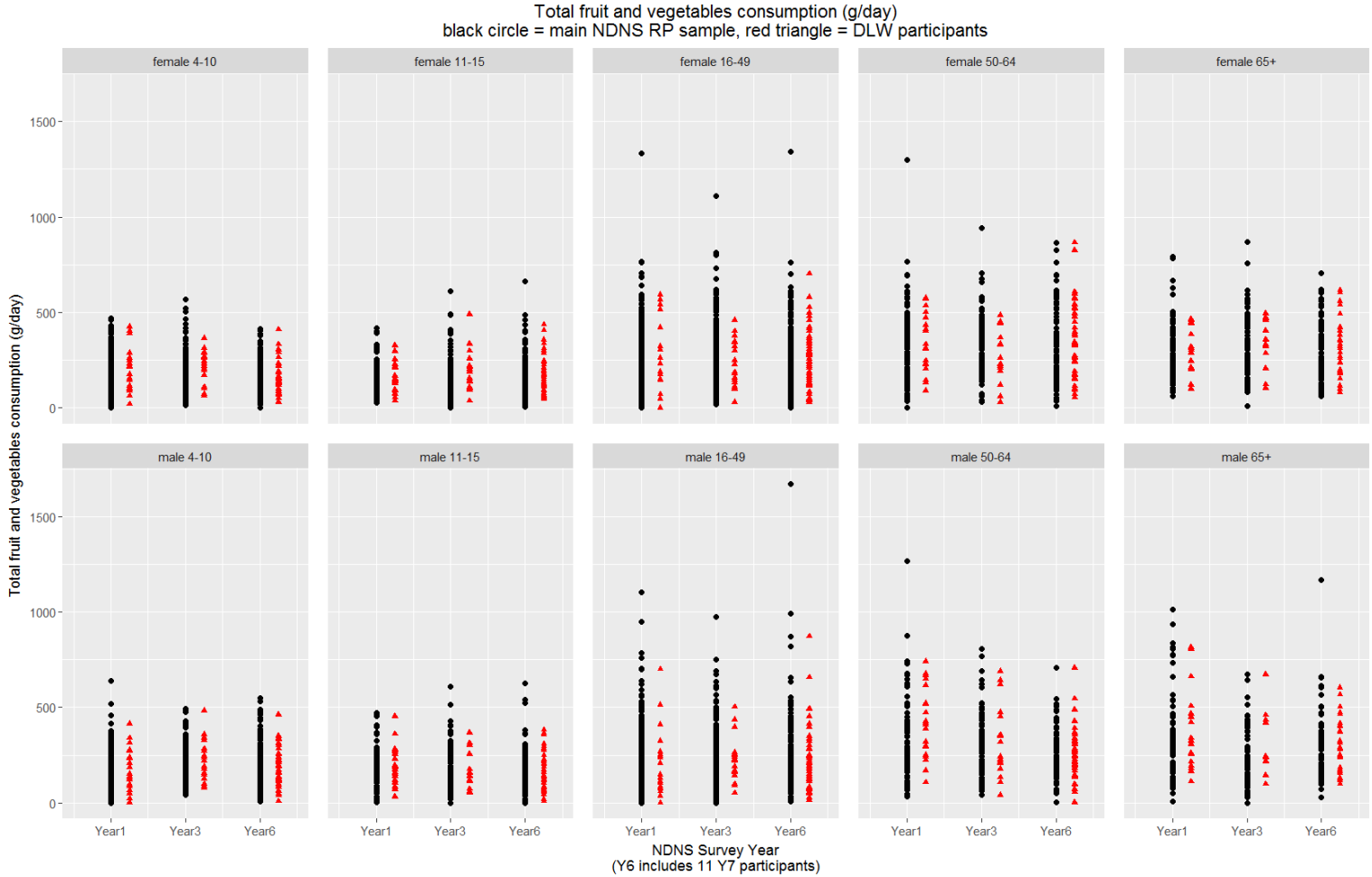


Figure X.4 Representativeness plot for free sugars intake of DLW recruits versus main NDNS RP recruits in Years 1 (2008/09), 3 (2010/11) and 6 and 7 (combined) (2013/14-2014/15)

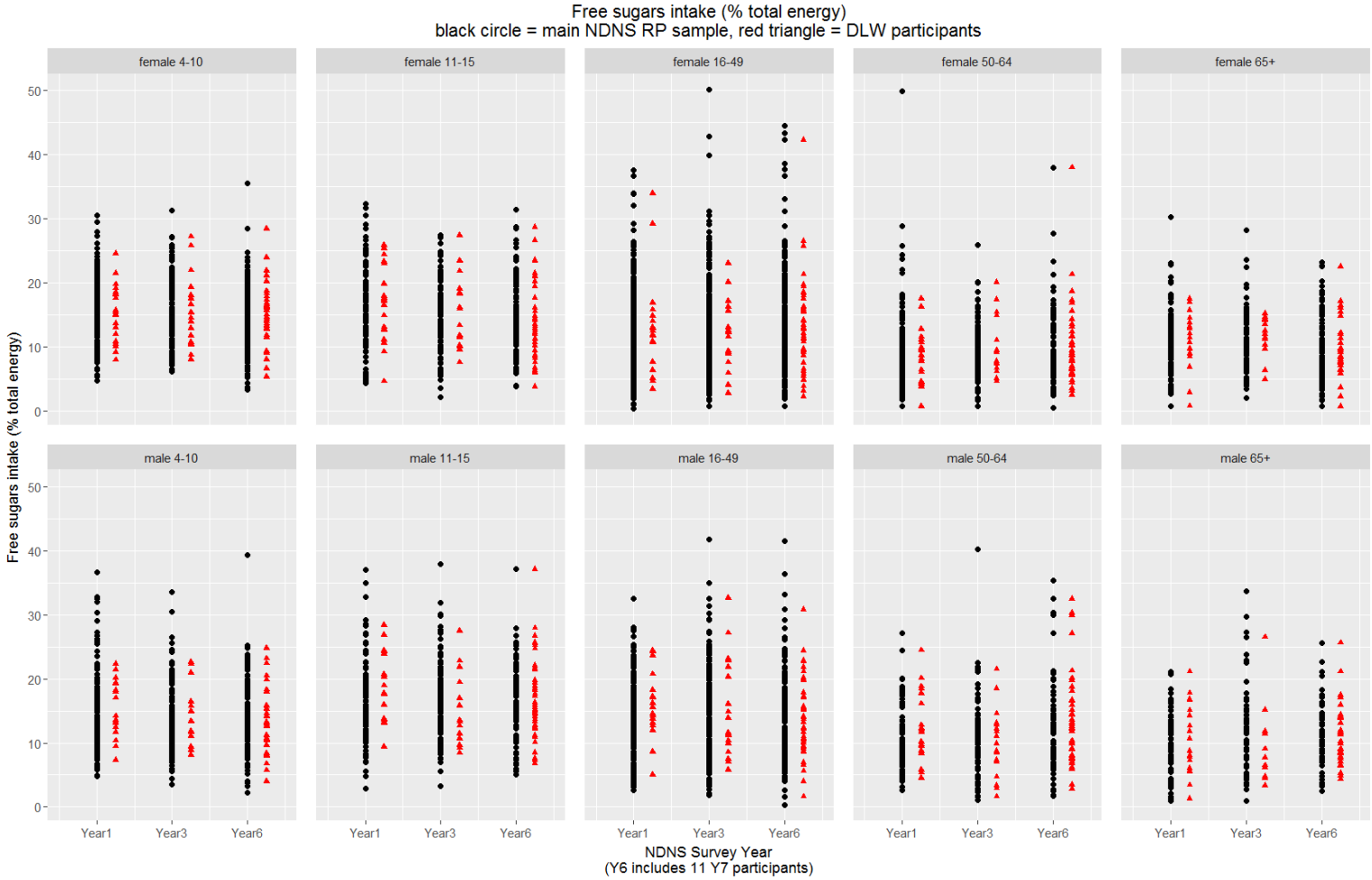
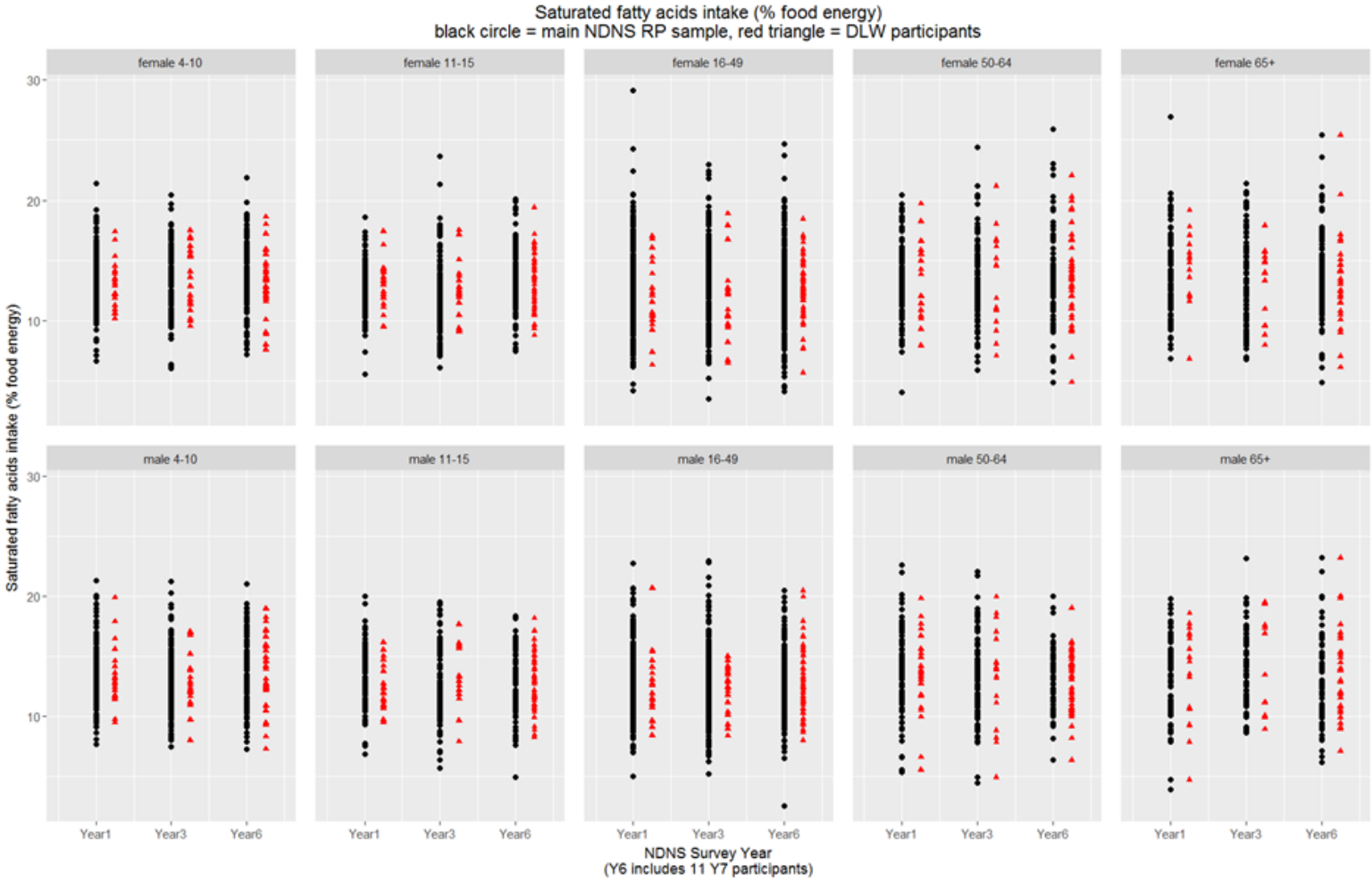


Figure X.5 Representativeness plot for saturated fatty acids intake of DLW recruits versus main NDNS RP recruits in Years 1 (2008/09), 3 (2010/11) and 6 and 7 (combined) (2013/14-2014/15)



c. Day of the week

In each year of the NDNS RP the dietary assessment protocol is for an estimated food and drink diary to be completed over 4 consecutive days. The survey is designed so that all days of the week would (as far as possible) be equally represented in recognition that energy and nutrient intakes differ by day of the week, and particularly between weekdays and weekend days. In the Years 1 to 4 (combined) dataset there was a slightly higher proportion of weekend days than weekdays.[1] In the Years 5 to 9 (combined) dataset each day of the week was equally represented.

In contrast, the DLW protocol was for participants to collect spot urine samples for 10 continuous days after dosing with stable isotopes. The period over which TEE was measured in the NDNS RP and previous NDNS assessments therefore included at least one weekend for all participants, and an extra Saturday for roughly 25% of the DLW sample.

Previous surveys[17] have shown that reported EI is higher on Saturdays and to some extent on Fridays and Sundays in some age groups. Since the measurement of EE by DLW always covered at least 1 weekend whereas the estimate of dietary EI in the NDNS RP 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 measured TEE. This is unlikely because, as explained above, DLW does not measure daily EE. It provides an integrated measure of TEE over all the days of measurement. An individual participant would have to do something extreme to increase or decrease TEE substantially on a single day for it to make a difference to the mean measurement. Therefore, day of the week is unlikely to have been a factor influencing the difference.

d. Food portion size and composition issues

It is possible that EI from some components of the diet may be underestimated due to portion size estimates or food composition assumptions used in the NDNS RP. In the NDNS RP participants are asked to provide information on the portion size of food eaten for all food and drink recorded in the diary. Adult participants are asked to record their portion sizes as household measures (e.g. tablespoon, teaspoon) and they are also provided with pictures of 15 frequently consumed foods as small, medium and large portion sizes as well as a glass size example, to guide their self-assessment. A different visual guide is provided for children. When individual adult diaries are coded, portion sizes are assigned using the Food Standards Agency's "Food Portion Sizes" reference book.[18] For children, age-appropriate portions are used based on the analysis of portion sizes consumed in previous NDNS based on weighed records.[19] Portion sizes are also obtained from packaging (such as for ready meals), or by undertaking specific projects to update portion size estimates. Portion sizes are continually monitored, including default portions (those used when no portion size is provided in the diary), and are updated where new information becomes available.

X.7 Application of the DLW method in the NDNS RP

Biases such as underreporting are inherent in self-reported dietary data but remain an area of ongoing concern and priority warranting further investigation. In some research EI are adjusted e.g. using Goldberg cut-offs.

However previous work examining sensitivity and specificity has shown that using single cut-off based on a single PAL to evaluate the EI of all subjects in a study can lead to misclassification of a proportion of subjects[20] and that using a single cut-off to attempt to identify low energy reporters may fail to account for bias at the upper end of the distribution of EI and EE.[21] In order to identify biased EI reporting at the individual level, and to avoid misclassification using a single cut-off, an estimate of TEE or activity should be obtained for each individual in a sample and the appropriate individual cut-off calculated and applied to their reported EI.[20] Therefore as TEE using DLW was only estimated in a sub-sample of the NDNS RP, self-reported energy and nutrient intakes have not been adjusted in this report. Approaches such as those outlined in the Eclipse report[22] are at an early stage of exploration and require further investigation prior to application for the NDNS RP.

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