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

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X.1 Introduction

This appendix presents an overview of methods and results from the doubly labelled water (DLW) sub-study of the NDNS RP and a summary of considerations relevant to the interpretation of these results.

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

In the NDNS RP, DLW was administered to a subgroup of survey participants, aged four years and over, following dietary data collection, which required recruiting 400 survey participants after completion of the food diary (200 survey participants in each of Years 1 and 3 of the survey), with the aim of achieving 20 in each sex and age reporting group.

The DLW method is an established method widely agreed to be the most accurate way of measuring energy expenditure in free-living individuals over one to two weeks, and hence detecting misreporting of energy intake (EI).[1,2] The methodology is objective and robust and demands relatively little from the participant. The NDNS RP is one of the few 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 analyses 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 Total Energy Expenditure (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 (^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 (i.e. $[rH_2O+rCO_2] - [rH2O] = rCO_2$). Energy expenditure 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 energy expenditure for the period of measurement and not data for individual days.

In healthy adult participants, if, for a given period of time, energy consumed in food matches total energy expended, they are in energy balance. In this circumstance, TEE is equal to energy intake (EI) and measures of habitual TEE can therefore be used to assess the level of misreporting of energy intake in habitual reported dietary data.[1,2] 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.[3,4]

In previous NDNS, with the exception of the NDNS survey of older adults (aged 65 years and over), TEE was measured in sub-studies prior to and separate from the main survey in order to validate the dietary method; hence there was no assessment of underreporting in the survey itself. For the adult survey of 2000/01,[5] a DLW component was included in a feasibility study to compare reported EI from the seven-day weighed dietary intake with TEE measured concurrently. Data on EI and TEE from DLW were available for 64 individuals.[6] The NDNS RP Comparison Study was conducted in 2007,[7] prior to the launch of the NDNS RP main stage fieldwork, to compare two dietary methods: four 24-hour recalls and a four-day estimated (unweighed) diary in 1,000 participants (500 for each method). As part of this comparison, TEE using DLW was measured in 160 participants, consisting of 80 individuals for each dietary method, subdivided into five reporting age groups: 4 to 10 years, 11 to 15 years, 16 to 49 years, 50 to 65 years and 65 years and over.[8]

In the NDNS RP, DLW was administered to a subgroup of survey participants, aged four years and over, spread between the same age groups as reported in the Comparison Study. The aim was to recruit approximately 10% of the survey participants i.e. approximately 400 out of a total of 4,000 participants taking part in the survey over Years 1 to 4. This was achieved by recruiting 200 survey participants each in Years 1 and 3 of the survey: 20 in each sex and age group. The protocol was the same as that in the NDNS RP Comparison Study in that the DLW component took place after but within one month (typically two to three weeks) of the dietary assessment period, with the DLW participants recruited at the third interviewer visit, when the completed food diaries were collected.

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

X.3 Number of participants in the DLW component of the NDNS RP

The recruiting targets for DLW for both Years 1 and 3 were 200 participants per year. In addition, the DLW participants (n = 10) from the Run In (the 'dress rehearsal' period of the NDNS RP from February to April 2008) were included with Year 1. 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. Table X.1 shows the total number of DLW participants recruited. In some groups the recruiting targets were not met, especially in Year 3. Smaller total numbers were recruited than planned in males aged 11 to 15 years and 65 years and over.

Table X.1 Number of DLW participants in the NDNS RP Years 1 and 3

Age group	Sex	Year 1	Year 3	Total
4-10 years	Male	21	20	41
	Female	21	20	41
11-15 years	Male	20	14	34
	Female	20	18	38
16-49 years	Male	20	18	38
	Female	21	19	40
50-64 years	Male	21	20	41
	Female	21	16	37
65+ years	Male	18	11	29
	Female	18	14	32
Total	Male	100	83	183
	Female	101	87	188

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. 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 Human Nutrition Research, Cambridge (HNR) 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 HNR, described in section X.4.2.

X.4.2 Isotopic analyses

Measurements of deuterium content of the samples were made using a GV Isoprime IRMS (GV instruments, Manchester, UK). This was done by equilibration of a 400µL aliquot of urine with approximately 3bar.mL hydrogen gas over a platinum catalyst. A 500µL aliquot of the sample and equilibration with CO_2 [9] 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)[10] from slopes and intercepts of the isotope disappearance curves based on urine samples collected on days 1 to 3 and 8 to 10. Basal metabolic rate (BMR) for each individual was estimated using the Schofield equations.[11] Physical activity level (PAL) was expressed as TEE divided by BMR.[10] This ratio removes virtually all the differences between individuals due to sex, age and body size.

X.5 Results of DLW analysis in the NDNS RP

As described earlier, if an individual is in energy balance their habitual EI equals their habitual total energy expenditure 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 energy intake and energy expenditure, 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 energy intake and measured energy expenditure, potentially due to underreporting of food intake or under eating during the dietary intake assessment.

Table X.2 presents the mean values for reported EI and measured TEE along with the ratio of EI:TEE. The results of the analysis of the DLW sub-study indicate good agreement between mean reported energy intake and mean measured energy expenditure 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 in the NDNS RP, mean EI:TEE was 0.73. Mean EI:TEE was 0.68 for male adults and 0.65 for female adults aged 16 to 64 years. Mean EI:TEE ranged from 0.64 for females aged 16 to 49 years at the lowest to 0.89 for girls aged 4 to 10 years at the highest. These findings are not inconsistent 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 NDNS RP Doubly Labelled Water Sub-Study (Years 1 and 3)

Age group	Sex	N	EI (kcal)	TEE (kcal)	TEE-EI	EI:TEE
4-10 years	Males	41	1624	1876	253	0.87
	Females	41	1564	1759	195	0.89
11-15 years	Males	34	2073	2714	641	0.76
	Females	38	1724	2394	670	0.72
16-49 years	Males	38	2274	3422	1148	0.66
	Females	40	1620	2537	917	0.64
50-64 years	Males	41	2173	3141	968	0.69
	Females	37	1598	2428	830	0.66
65+ years	Males	29	1915	2708	793	0.71
	Females	32	1558	2167	608	0.72

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.[12] The NDNS RP and previous NDNS are unique in their inclusion of DLW as an objective biomarker to validate energy intake estimated from reported food and drink consumption. A number of different factors may contribute to why mean reported energy intake is lower than measured energy expenditure in the NDNS RP, including participant underreporting. A summary of other considerations is presented below.

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

Unlike earlier NDNS, the NDNS RP and the RP Comparison Study included the DLW sub-study in the main survey protocol. This may have certain implications for sampling, compliance and the extent of underreporting. Furthermore, to minimise participant burden, the DLW protocol was carried out after the diary recording of food and drink consumption, generally two to three weeks later, rather than being concurrent with it as was the case in the sub-studies carried out in previous NDNS and in other studies where TEE was measured using the DLW method.[13,14] Efforts were made in the NDNS RP to encourage participants to 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 recording dietary intake. The tendency to over-report physical activity has also been observed when assessed by questionnaire and activity monitors.[15,16,17] However, the DLW method for measuring total energy expenditure is much less subject to bias through participants changing their activity levels.

b. Representativeness of the DLW sample

The DLW participants represent a small proportion of the core NDNS RP sample (Years 1 to 4). Interviewers invited fully productive participants to take part in the DLW sub-study until age/sex quotas were filled. Because of the cost and limited supplies of the stable isotope, interviewers were given the discretion to invite only those participants who they considered were likely to comply with the protocol. Analyses have been carried out to assess the representativeness of the DLW sample in relation to the core survey sample.

No significant differences were found between the DLW sample and the core survey sample for demographic characteristics (ethnicity, body mass index (BMI), socio-economic group and smoking status). Food consumption differences were examined between the core NDNS RP sample and the NDNS RP DLW sub groups, and no obvious patterns were identified. Data were also checked for participants reporting weight-reducing diets, because DLW is based on the assumption that weight is stable during the reporting period. There were no clear differences in the proportion of the DLW sub group reporting a weight reducing diet compared with the core NDNS RP sample.

c. Day of the week

The NDNS RP dietary assessment protocol is for the food and drink diary to be completed over four 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 change by day of the week, and particularly between weekdays and weekend days. However, as explained in Chapter 5 of this report, there was a slightly higher proportion of weekend days than weekdays in the Years 1 to 4 combined data. The previous adult NDNS survey protocol[5] was for a seven-day dietary record and therefore included both weekend days. The 2007 NDNS RP Comparison Study was similar to the NDNS RP protocol of four days.

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%.

Previous surveys[18] 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 energy expenditure by DLW always covered at least one 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 energy expenditure. It provides an integrated measure of TEE over all the days of measurement. An individual participant would have to do something very extreme to increase or decrease TEE significantly 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 food composition or portion size estimates used in the NDNS RP. Inspection of changes of single components over time suggest that misreporting of protein may be less of a problem than for other macronutrients. This is because protein is present in many core foods and mean intake of protein in the UK has changed little over time. Underestimates of fat and carbohydrate intake (foods high in fat and/or sugar) have been suggested as possible reasons for underreporting of intake in the past.[19] As a consequence, underestimates of portion size and energy content of foods that do not contain protein may contribute more to underreporting in the NDNS

RP. Specific examples include: oils used for cooking or spreading fats; soft drinks and confectionery; and alcoholic beverages.

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) 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 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.[20] For children, age-appropriate portions were used based on the analysis of portion sizes consumed in previous NDNS based on weighed records.[21] 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 NDNS RP

Previous work examining sensitivity and specificity has shown that using single cut-off based on a single PAL to evaluate the energy intake of all subjects in a study can lead to misclassification of a proportion of subjects[22] 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 energy intake and expenditure.[23] In order to identify biased energy intake reporting at the individual level, and to avoid misclassification using a single cut-off, an estimate of total energy expenditure or activity should be obtained for each individuals in a sample and the appropriate individual cut-off calculated and applied to their reported EI.[22] Therefore as total energy expenditure using DLW was only estimated in a sub-sample of the NDNS RP, there has been no attempt to adjust the self-reported energy and nutrient intakes presented in this report.

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[3] 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).

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