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AN EXTENSIVE EVALUATION OF THE VALIDITY OF REPORTED ENERGY INTAKES IN THE NORTH/SOUTH IRELAND FOOD CONSUMPTION SURVEY

by

Maureen J. McGowan

A thesis presented for the degree of

Doctor of Philosophy (Ph.D.)

The University of Dublin, Trinity College

Department of Clinical Medicine

University of Dublin, Trinity College

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DECLARATION

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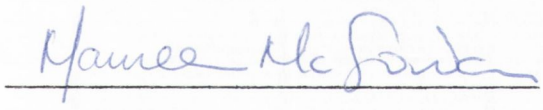

Maureen McGowan

SUMMARY

The North/South Ireland Food Consumption Survey (NSIFCS) was conducted between 1997 and 1999, on a representative sample of 1379 adults from the Republic of Ireland and Northern Ireland, aged 18 to 64years. Food intakes were collected using a 7 day food diary and information on health, lifestyles, physical activity and attitudes to health were collected using a series of questionnaires while anthropometric measurements were taken.

The overall aim of this thesis was to examine the validity of reported energy intakes. Mean daily energy intake was 11.0 MJ in men and 7.6 MJ in women. The mean ratio of energy intake/estimated basal metabolic rate (EI/BMR_{est}) was 1.38, which indicated energy underreporting. In addition, mean EI/BMR_{est} was significantly higher in men than in women ($P<0.01$) and decreased significantly with increasing age and body mass index ($P<0.05$) suggesting that energy underreporting was higher in women than in men and that energy underreporting increased with age and adiposity (Chapter 3).

The validity of energy intakes can be assessed by comparing intakes to energy expenditure. This principle is used in the Goldberg equation, which calculates cut-offs for EI/BMR, below which energy intakes are underreported, by comparing EI/BMR to a physical activity level. Chapter 4 describes how an estimated physical activity level (ePAL) was calculated from a self administered physical activity questionnaire designed to measure habitual activity over the previous 12 months. The physical activity data were originally presented as total METS representing activity at work, in recreation and in selected 'household' work. The present author further examined the data in detail to ensure that all activities over the 24 hour day were included. Total METS was recalculated and expressed as a multiple of BMR i.e. ePAL. The mean population ePAL was 1.81 in men and 1.69 in women, which is comparable to published PALs from doubly labelled water measurements in adults.

In chapter 5, the Goldberg cut-offs for EI/BMR_{est} were recalculated using the FAO/WHO/UNU (1985) PALs for low, medium or high activity and applied to men and women categorised as low, medium or high activity according to their own ePAL. The prevalence of underreporting increased to 30% using this method from 19% when a PAL of 1.55 was assumed for the population. Being female and overweight/obese was

independently associated with underreporting using both methods. Excluding energy underreporters, according to both methods, did not affect the proportion of energy from macronutrients. It did however affect the interpretation of nutrient adequacy in the population e.g. the proportion of those with fat intakes $\leq$ 35% of food energy decreased from 31% to 28% in men and from 34% to 26% in women when energy underreporters identified using population-specific ePALs, were excluded. In addition, the proportion of women aged 18-35 yrs and 36-50 yrs meeting the average requirement for iron decreased from 51% to 39% and 46% to 36% respectively after underreporters, identified using this method, were excluded.

This examination of energy underreporting was extended in chapter 6 by quantifying body weight changes over the food diary period. In contrast to the increasing prevalence of obesity in Irish adults, there was a mean weight loss of -0.05kg in the 921 respondents included in this analysis. Respondents expected to lose weight (dieters and those who were ill) had been excluded. A mean weight loss was seen in men and women in all age groups, in underreporters and in valid reporters and was not related to survey duration. Weight loss suggested undereating and the cumulative adjustment of energy intakes for weight loss, for weight gain in underreporters and to eliminate energy underreporting estimated that 66% – 70% of energy intake had been reported among underreporters and that the remaining 30% was equally due to undereating and underrecording.

In summary, the analysis in this thesis demonstrates the use of physical activity data and repeated body weight measurements before and after food intake recording in identifying underreporters and in understanding the relative contribution of undereating and underrecoding to underreporting. It also highlights the importance of examining the influence of energy underreporting to correctly interpret food and nutrient intakes.

DEDICATION

To my mother Anna, with love and thanks

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ABBREVIATIONS

ANOVA	Analysis of Variance
BMI	Body Mass Index
BMR	Basal Metabolic Rate
BMR_{est}	Estimated Basal Metabolic Rate
CFSII	Continuing Survey of Food Intakes by Individuals
CI	Confidence Interval
DLW	Doubly Labelled Water
DNSBA	Dietary and Nutritional Survey of British Adults
DRV	Dietary Reference Value
EAR	Estimated Average Requirement
EE	Energy Expenditure
EI	Energy Intake
EI/BMR	Ratio of Energy Intake to Basal Metabolic Rate
EI/BMR_{est}	Ratio of Energy Intake to estimated Basal Metabolic Rate
ePAL	Estimated Physical Activity Level
EPIC	European Prospective Investigation into Cancer and Nutrition
FAO	Food and Agriculture Organisation
FFQ	Food Frequency Questionnaire
IUNA	Irish Universities Nutrition Alliance
MET	Metabolic Equivalent
N	Nitrogen
NHANES	National Health and Nutrition Examination Survey
NSIFCS	North South Ireland Food Consumption Survey
PAL	Physical Activity Level
PAR	Physical Activity Ratio
RMR	Resting Metabolic Rate
TEE	Total Energy Expenditure
UN	Urinary Nitrogen excretion
UNU	United Nations University
WHO	World Health Organisation

PUBLICATIONS

The following publications have been derived from the work of this thesis.

Papers

McGowan MJ, Harrington KE, Kiely M, Robson PJ, Livingstone MBE, Gibney MJ. An evaluation of energy intakes and the ratio of energy intake to estimated basal metabolic rate (EI/BMR_{est}) in the North/South Ireland Food Consumption Survey. *Public Health Nutrition* 2001; 4(5A):1107-1116.

Abstracts

McGowan MJ, Harrington KE, Gibney MJ, Kiely M, Flynn A, Robson PJ, Livingstone MBE & Strain JJ. Energy intakes in the Republic of Ireland: analysis of the North/South Ireland Food Consumption Survey. *Proceedings of the Nutrition Society,* 2001, 60: 17A

McGowan MJ, Harrington KE, & Gibney M. The use of physical activity data in the identification of low energy reporters in the North/South Ireland Food Consumption Survey. *Proceedings of the Nutrition Society,* 2001, 60: 157A

McGowan MJ, Harrington KE, Flynn A, Strain JJ & Gibney MJ. Energy intakes are not affected by survey duration in Irish adults but are affected by day of the week *Annals of Nutrition & Metabolism,* 2001, 45: (suppl. 1) 154A

Chapter 1

Introduction

Accurate measures of food and nutrient intakes are necessary to correctly interpret the association between diet and health. The validity of food and nutrient intakes is primarily investigated through comparing reported energy with energy requirements where energy intake is a proxy measure of food intake. This approach has shown that self reported food intakes are frequently underestimated by all dietary assessment methods. This underestimation is called 'underreporting' throughout this thesis.

1.1 Identifying Underreporting in Food Intake Studies

Underreporting of energy intakes has been identified by five different external markers of intake:

1. Comparing self reported energy intake to energy intake required to maintain weight in metabolic and intervention studies.
2. Comparing nutrient intakes to urinary biomarkers.
3. Comparing reported energy intake to free living energy expenditure (EE) using the doubly labelled water method.
4. Comparing energy intake to estimates of energy expenditure
5. Comparing energy intake (EI) and EE when both are expressed as multiples of basal metabolic rate (BMR) using the Goldberg cut-offs.

Each of these methods will be explored

1.1.1 Weight Maintenance Studies

A number of weight maintenance studies have detected energy underreporting (Mertz *et al.*, 1991; Pannemans & Westerterp, 1993; Haraldsdöttir & Sandstrom, 1994; deVries *et al.*, 1994). These studies are all similar in design. Subjects first complete a food record and are then fed foods equivalent to their self-reported energy intake over an intervention period. Energy intakes over the intervention period are subsequently adjusted to maintain body weight. Energy underreporting is detected by comparing reported energy intake to the actual energy intake required to maintain weight.

1.1.2 Urinary Biomarkers

Urinary nitrogen is the biomarker most used in measuring the validity of dietary intakes where urinary nitrogen excretion (UN) is compared to nitrogen intake (N) over the same time frame by the ratio UN:N. A high ratio indicates that protein intake was underreported. A ratio of 0.81 is considered to represent a valid food record (Bingham & Cummings, 1985) but a ratio of greater than 1.0 has been used in some studies to

identify individual underreporters (Black *et al.*, 1997). The method is dependent on complete urine collections, usually over 24 hours, and assumes that subjects are in nitrogen balance with no accumulation of nitrogen due to growth or repair of muscle and no loss due to starvation, dieting or injury (Bingham, 2003). Urinary potassium has also been used to validate potassium intakes in the same way as urinary nitrogen (Heerstrass *et al.*, 1998).

1.1.3 Energy Expenditure from Doubly Labelled Water Measurements

The doubly labelled water method to measure free living energy expenditure allows reported EI to be compared to EE measured over the same time frame (Schoeller, 1990). Subjects drink a known amount of water labelled with two isotopes ($^{2}H^{18}O$) hence the name doubly labelled water. Deuterium (^{2}H) is eliminated from the body as water while oxygen^{18} (^{18}O) is eliminated as water and carbon dioxide. The difference between the two elimination rates, measured in urine, is a measure of carbon dioxide production. As carbon dioxide is the end product of substrate oxidation for energy production, energy expenditure can be calculated from calorimetric equations (Wilmore, 2001; Schoeller, 1990). Subjects must be in energy balance i.e. not losing or gaining weight for EI to match EE using this method (Schoeller, 1990). The technique has been widely used during the late 1980s and 1990s to compare EI and EE (Hill & Davies, 2001) but has generally been reserved for smaller studies as it is expensive and requires technical expertise (Livingstone, 1995). Energy intakes below EE have been categorised as underreported.

1.1.4 Estimated energy expenditure

Reported energy intakes have also been compared with estimates of energy expenditure, other than doubly labelled water measurements and the energy required for weight maintenance. Indirect calorimetry in a metabolic setting has been used to measure energy expenditure for comparison with energy intakes (Lindross *et al.*, 1999; Drougas *et al.*, 1992; Visser *et al.*, 1995; Asbeck *et al.*, 2002). In the free living situation, expenditure has been estimated from activity diaries (Körtzinger *et al.*, 1997; Arroll *et al.*, 1991), questions on physical activity (Heitmann & Lissner, 1995; Høidrup *et al.*, 2002), accelerometers (Goris *et al.*, 2001a) and from a predictive equation based on doubly labelled water measurements of EE (Johnson *et al.*, 1994). The precision and validity of these techniques in measuring energy expenditure is lower than that for

doubly labelled water but they are more practical than DLW in larger studies (Livingstone & Black, 2003).

1.1.5 The Goldberg cut-offs for identifying invalid energy intakes

This section describes the Goldberg cut-offs to identify energy underreporting and chronologically documents the development of these cut-offs by Goldberg, Black and colleagues at The University of Cambridge, UK. This section is detailed as it is the basis for much of the work in this thesis. In 1991, Goldberg *et al.*, (1991) introduced the idea of expressing energy intake, from dietary assessment, as a multiple of basal metabolic rate (EI/BMR) and devised cut-offs for EI/BMR below which energy intake for "a person of a given sex, age and body weight could not live a normal lifestyle". These cut-offs were presented in 2 forms (cut-off 1 and cut-off 2).

Cut-off 1 tested whether reported energy intakes represented habitual intake and was set at 1.35 where BMR was measured rather than estimated. This value (1.35) was the mean physical activity value (PAL) from nine whole-body calorimetry studies on 207 sedentary subjects. Cut-off 1 does not take into consideration day-to-day variation in energy intake and variation in physical activity levels. Cut-off 2, however, tests whether reported energy intakes are "a plausible measure of the food consumed during the actual measurement period". Goldberg *et al.*, (1991) presented a formula for the calculation of cut-off 2 and also presented two tables of calculated cut-off 2 values for different sample sizes (1-2000), for different periods of food intake measurement (1-28 days) and according to whether BMR was measured or predicted by the Schofield equations (Schofield *et al.*, 1985). The formula for the calculation of cut-off 2 represents either the lower 95% or 99.7% confidence limit of agreement between EI/BMR and a Physical Activity Level (PAL) of 1.55 taking into consideration the within-person variation in energy intake, the within-person variation in the estimation or prediction of BMR and the within-person variation in PAL.

The formula is :

$$\text{EI/BMR} < \text{PAL x exp}\left[s.d._{\min} x \frac{(S/100)}{\sqrt{n}} \right]$$

$$S = \sqrt{\frac{CV_{IW}^{2}}{d} + CV_{B}^{2} + CV_{P}^{2}}$$

PAL = Physical Activity Level

d = number of days of dietary assessment
n = sample size
$s.d._{min}$ = -2 for 95% lower confidence limit
CV_{IW} = within-person co-efficient of variation in energy intake
CV_B = within-person co-efficient of variation in predicted BMR
CV_P = within-person co-efficient of variation in PAL

The within-person co-efficient of variation of energy intake used was 23%. This was the mean within-individual co-efficient of variation from 17 separate studies of 15 different population groups from Europe, America and Australia was 23% (Bingham, 1987). The within-person co-efficient of variation for measured BMR used was 2.5% as had been reported by Prentice *et al.*, (1989). The within-person co-efficient of variation for predicted BMR using the Schofield equations was 8% as reported by Schofield *et al.*, (1985). The value used for the within-person co-efficient of variation for PAL was 12.5% as had been assumed by the FAO/WHO/UNU (1985) report on energy requirements. The PAL used in the formula for the calculation of cut-off 2 was 1.55. This value was proposed by FAO/WHO/UNU (1985) as a sedentary PAL and was used in the formula in the absence of other accepted information on PALs in populations. Goldberg *et al.*, (1991) acknowledged that this PAL was lower than the mean value of 1.67 from seven doubly-labelled water studies of 105 individuals. It was suggested that if the subjects in a study are known to be more active then a different PAL could be used

The cut-off 2 value for a population of 1500 respondents with 7 days of food intake data is 1.54 (95% confidence limit). This value (1.54) represents the minimum mean expected value of EI/BMR_{est} in this population. When each individual in the population is considered separately, the cut-off 2 value for n=1 with 7 days of food intakes is 1.1 (95% confidence limit). Individuals in this population with an EI/BMR_{est} below this value are not considered to have reported valid energy intakes for the period of food intake measurement. The cut-offs have been widely used in the identification of bias relating to underreporting in food intake studies and for the identification of individual underreporters by using the relevant cut-off when n=1.

In an accompanying paper, Black *et al.*, (1991) evaluated the results of 37 published dietary surveys using the Goldberg cut-offs. These dietary surveys were from the United Kingdom (n = 16), Ireland (n = 2), other European countries (n = 14) and the USA (n = 5) and represented 68 subgroups categorised by sex and method of dietary

assessment. Of the 32 female subgroups, only 5/32 (16%) had mean EI/BMR_{est} ratios above the study-specific cut-off as defined by Goldberg *et al.*, (1991) and, of the 34 male subgroups, 17/34 (54%) had mean EI/BMR_{est} ratios above the relevant study-specific cut-offs. In acknowledgement of the higher PAL of 1.67 (1.78 in men, 1.62 in women) from 7 doubly labelled water studies available at the time, Black *et al.*, (1991) recalculated the cut-offs based on a PAL of 1.78 in men and 1.62 in women and found that a lower proportion of both the female studies (3/32 (9%)) and the male studies (2/34 (6%)) had a mean EI/BMR_{est} ratio above the relevant cut-off. Black *et al.*, (1991) recommended that a physical activity questionnaire is used in food intake studies to give guidance on suitable PALs for evaluating either individual of group energy intakes.

During the following years, many additional studies used the doubly labelled water method to measure free-living energy expenditure. In 1996, Black *et al.*, published information on PALs from all available doubly labelled water studies representing 574 individuals. Mean PAL values for 18-64 year olds are presented in Table 1.1

Table 1.1. Physical Activity Levels from an analysis of doubly labelled water measurements of energy expenditure (Black *et al.*, 1996)

	PAL Mean (SD)
Males 18-29 y (n = 56)	1.85 (0.33)
Males 30-39y (n = 36)	1.77 (0.31)
Males 40-64y (n = 15)	1.64 (0.17)
Females 18-29 y (n = 89)	1.70 (0.28)
Females 30-39y (n = 76)	1.68 (0.25)
Females 40-64y (n = 47)	1.69 (0.23)

The mean PAL value from each of the groups in Table 1.1 is greater than the FAO/WHO/UNU (1985) value of 1.55 for a sedentary population used in the Goldberg cut-offs (Goldberg *et al.*, 1991).

In 1997, Black *et al.*, compared the Goldberg cut-offs to the direct comparison of energy intake to energy expenditure (DLW) in identifying underreporters, in three groups of subjects: 18 women aged 50-65 years, 27 men aged 55-87y and 11 post obese

subjects. Three cut-off calculations were used based on a PAL value of 1.55, a study specific PAL (women 1.66, men 1.86 and post obese 1.59) and a subject-specific PAL. At a group level the cut-offs using a PAL of 1.55 only identified underreporting in the post obese group. The cut-offs calculated from the study-specific PAL identified energy underreporting in all 3 groups as did the direct comparison of energy intake (EI) to energy expenditure (EE). On an individual level, 7 women and 8 men were identified as underreporters by comparing EI and EE. Only two women (2/7 = 29%) and two men (2/8 = 25%) were identified by the cut-off based on PAL = 1.55. When a study specific PAL was used, four women (4/7 = 57%) and five men (5/8 = 62%) were identified as underreporters leaving 3 women and 3 men not identified as underreporters. This work suggested that knowledge of a subject's individual PAL was needed to identify all underreporters in a population.

Throughout the 1990s, the Goldberg equation was widely used to identify energy underreporters. In 2000, Black acknowledged that the cut-offs were not always correctly applied and subsequently restated the principles of the cut-offs and re examined the values to be used for each parameter in the equation (Black, 2000a). The value suggested for the within subject variation in predicted BMR was 8.5% instead of 8% in 1991. This revised figure was based on the standard errors for predicting BMR expressed as percentage of mean BMR from data presented by Schofield *et al.*, (1985). The variation in physical activity was described as the total variation in PAL i.e. including between-person, within-person and methodological variations in PAL. The value chosen was 15%, which was the average variation in PAL from the 74 doubly labelled water studies presented in Table 1.1 (Black *et al.*, 1996). This was an increase from the value of 12.5% in 1991, taken from the FAO/WHO/UNU (1985) report on energy requirements, which cited only one study to support the value of 12.5%. The value for the within person co-efficient of variation in energy intake remained the same at 23%. Changing the values for the parameters in the equation widened the confidence limits for a given PAL e.g. the lower 95% confidence limit (cut-off) to identify individual underreporters in a sample of 1500 subjects with 7 days of food intake data was 1.05 compared to 1.1 previously.

Black (2000a) made two further comments on the use of the cut-offs. In the first place, cut-off 1 (1.35) for 'habitual intake' was deemed obsolete, as it did not take into consideration the variation inherent in the parameters in the equation. In addition, it had

contributed much confusion in the use of the cut-offs. Secondly, choosing a specific PAL for the population allows the upper 95% confidence limit of agreement between EI/BMR and PAL to be calculated. This is the cut-off above which energy intakes are also not valid and these subjects are called overreporters.

In a related paper, Black (2000b) explored the sensitivity and specificity of the Goldberg cut-offs, using the revised parameters, in identifying underreporters compared to the direct comparison of energy intake and energy expenditure as measured by DLW. The analysis was based on 22 studies of energy intakes, BMR and EE (DLW) on a total of 429 subjects. Of the 22 studies, 16 measured energy intakes from weighed food records of 2 to 14 days, 4 from estimated records, 1 from a diet history and 1 from a combination of methods. The ratio of EI:EE defined underreporters (EI:EE < 0.76), acceptable reporters (EI:EE 0.76-1.24) and overreporters (EI:EE > 1.24). These values were calculated from the Goldberg equation using measured PAL and the co-efficient of variation for DLW energy expenditure (Black & Cole, 2000). Based on these definitions, 34% of the 429 subjects were underreporters, 62% were acceptable reporters and 4% were overreporters. Four different strategies for identifying under and over reporters using the Goldberg cut-offs using different PALs were investigated. Sensitivity of the cut-offs was defined as the proportion of underreporters correctly identified and specificity as the proportion of non underreporters correctly identified. In the first strategy, the sensitivity of the cut-offs from a single PAL of 1.55 was low at 0.50 in men and 0.52 in women while specificity was high at 1.00 and 0.99. The second strategy used four different PALs, 1.65, 1.75, 1.85 and 1.95. Using these PALs traded specificity for sensitivity e.g. the cut-off based on a PAL of 1.95 identified 76% of men and 85% of women underreporters while specificity was 0.87 and 0.78 respectively. The third strategy used the mean age and sex PALs from Black *et al.*, (1996) as presented in Table 1.1. These did not improve the sensitivity of the cut-offs. The final strategy was the most effective as it improved sensitivity without any loss of specificity. It assigned subjects to low, medium or high activity categories and calculated cut-offs for 3 different PALs. These PALs were the FAO/WHO/UNU (1985) PALs of 1.55, 1.78 and 2.10 for men and 1.56, 1.64 and 1.82 for women. The sensitivity of the cut-offs using these PALs was 0.74 in men and 0.67 in women with specificity at 0.97 and 0.98 respectively.

Blacks work (2000a; 2000b) concluded with the practical application of the Goldberg cut-offs. The main recommendation was to ensure that physical activity was measured in studies of food intake to choose the most applicable PALs to use in the formula. In large studies, a questionnaire that allows subjects to be classified as low, medium or high activity was recommended. In smaller studies ($n < 100$), direct measurements of energy expenditure were recommended.

1.2 Prevalence of Underreporting

1.2.1 Weight Maintenance Studies

The prevalence of energy underreporting from five weight maintenance studies was 5% to 18% (Mertz *et al.*, 1991; Pannemans & Westerterp, 1993; Haraldsdöttir & Sandstrom, 1994; deVries *et al.*, 1994). Mertz *et al.*, (1991) reported that only 11% of subjects correctly estimated their energy requirements while 81% underestimated and 8% overestimated their requirements. The mean difference between reported energy intake and energy requirement was an 18% underestimation. While the mean difference between EI and energy to maintain weight in the four other studies was lower (5% to 10%), all studies showed an underestimation of energy requirements from self reported food intakes.

1.2.2 Urinary Biomarkers

Comparing nitrogen intake to urinary nitrogen excretion obviously can only measure the validity of protein intakes. If protein intake is underreported then, by definition, energy intakes are also underreported. There is evidence, however, that protein intake is underreported to a lesser extent than total energy intake (Black *et al.*, 1995; 1997; 2000). The mean underestimation of protein in these three studies was -2% for protein and -14% for energy.

1.2.3 Doubly Labelled Water Studies

Hill and Davies (2001) reviewed studies between 1986 and 2000 that compared self reported EI and EE measured by the doubly labelled water method technique in adults, children, the obese and athletes. In order to summarise their findings here, the 24 studies in adults are reviewed according to dietary assessment method. A total of 14 studies measured food intake by weighed records of between 3 and 14 days and EI was underestimated, within the range of 13% to 26% in 10 of these studies. In two of the studies in young lean adults, EI was very close to EE (1% to 2% greater) (Prentice *et*

al., 1986; Schulz *et al.*, 1989). In the other two studies, EI was underestimated in restrained eaters while overestimated in unrestrained eaters (Bathalon *et al.*, 2000) and underestimated in 'small eaters' while overestimated in 'large eaters' (Clarke *et al.*, 1994). The concept of restrained eating will be discussed in further detail later. Energy intakes were underestimated by 12% to 14% in the 5 studies that used estimated food records (3 to 7 days) and by 10% to 22% in four of the five studies that used 24 hour recalls. One of the 24 hour recall studies (Riumallo *et al.*, 1989) reported very close agreement between EI and EE when 24 hour recalls were repeated on seven consecutive days. Only one study used the dietary history method and energy intake was underestimated by 12% (Rothenberg *et al.*, 1998). Two studies measured EI by food frequency questionnaire (FFQ). Bathalon *et al.*, (2000) found that EI from a FFQ was underestimated in restrained and unrestrained eaters by 14% and 8% respectively. Sawaya *et al.*, (1996) used two FFQs in young and older women and reported that one underestimated EI in both age groups while the other underestimated EI in younger women (16%) and overestimated EI in the older women (7%).

In the 12 DLW studies on children, the vast majority showed that EI was underestimated compared to EE by 2% to 40%. There was evidence that EI was better reported in younger children (Livingstone *et al.*, 1992) and when food intake was reported by an adult on a child's behalf (Barden *et al.*, 2000). In the seven studies reviewed of obese adults and adolescents, all reported that EI was underreported by 19% or more (19% to 59%). In the nine studies on athletes during training or competition EI was also underreported in comparison to EE within the range of 1% in cross country skiers (Sjödin *et al.*, 1994) to 43% in elite swimmers (Trappe *et al.*, 1997). The majority of studies reported that EI was underreported by 13% to 35%.

1.2.4 Estimated Energy Expenditure

Table 1.2 outlines twenty studies of which 4 compared energy intake to energy expenditure measured by indirect calorimetry and 16 studies that compared energy intake to estimated energy expenditure using a variety of methods. Most of these 16 studies multiplied estimated or measured basal metabolic rate (BMR) with activity factors derived using different methods. All of the studies either present the difference between EI and EE or calculate the prevalence of underreporting (usually defined as EI less than EE). A few report the prevalence of overreporting (EI greater than EE). The criteria for defining underreporting in individual studies is included in Table 1.2.

Table 1.2 Energy underreporting in studies that measured energy expenditure by means other than doubly labelled water.

Author	Sample	Energy Intake	Energy Expenditure	Under-reporting	Overreporting
Körtzinger *et al.*, 1997	50 adults non-obese	7 day record Diet history	Measured RMR + PA from activity diaries	EI/EE < 1: 7 day record: 48% URs Diet history: 48% URs Both: 34% URs	-
Goris *et al.*, 2001b	34 adults Elderly	Two 7 day records	Measured BMR and PA from accelerometer	EI/EE < 1: First Diary: 21% URs Second Diary: 27% URs	-
Lindroos *et al.*, 1999	29 adults overweight/ obese	Diet questionnaire	24 hr EE by Indirect Calorimetry	EI < EE by 1%	-
Heitmann & Lissner, 1995	323 adults Denmark 1987/88	Diet history	Estimated BMR and PA questions	EI < EE by 24% (men) and 22% (women)	-
Heitmann *et al.*, 2000	122 adults Denmark 1993/94	Diet history	Estimated BMR and PA questions	EI < EE by 22% (men) and 19% (women)	-
Goris & Westerterp, 1999	24 dietitians	7 day WR	Measured BMR and PA from accelerometer	EI < EE by 16%	-
Arroll *et al.*, 1991	150 adults New Zealand	7 day record	7 day PA diary	EI < EE by 17%	-
Asbeck *et al.*, 2002	83 young adults	7 day record	REE (indirect calorimetry) x PAL 1.5	EI/EE < 0.8: 37% URs (49% women, 14% men)	EI/EE > 1.2: 8% ORs
Drougas *et al.*, 1992	24 adults	2 week record	24 hr EE by indirect calorimetry	EI < EE by 206 kcal/day	-
Gilliat-Wimberley *et al.*, 2001	32 adults USA	7 day WR	Measured RMR + 7 day activity record	EI < EE by 24% (active women) and by 5% (sedentary women)	-
Johnson *et al.*, 1994	137 older adults. USA	3 day record	Prediction equations previously derived from DLW measurements of TEE	EI/EE < 1: URs; 12 % (men), 24% (women)	EI > EE Prevalence not reported
Lindroos *et al.*, 1993	45 obese, 19 non-obese adults	4 day record Diet history	Measured BMR and PA from questionnaire	EI < EE by 4%	-

Table 1.2 (cont/d) Energy underreporting in studies that measured energy expenditure by means other than doubly labelled water.

Author	Sample	Energy Intake	Energy Expenditure	Under-reporting	Overreporting
Rothenberg *et al.*, 1998	12 adults 73 years	Diet history	1.DLW 2. Heart rate monitoring 3. Activity diary	EI/EE < 0.79: 1. 33% URs 2. 25% URs 3. 33% URs	EI/EE > 1.21: 1. 8% ORs 2. 17% ORs 3. 17% ORs
Sánchez-Castillo *et al.*, 2001	47 women Mexico	7 day WR	Measured or estimated BMR + PA diary	EI < EE by 24% Urban women) and by 17% (rural women)	-
Visser *et al.*, 1995	12 elderly women	Diet history	EE in respiration chamber	EI < EE by 12%	-
Ortega *et al.*, 1996	126 female students Spain	7 day record	BMR x activity ratio	EI < EE by 3-16% in those who wanted to lose weight. EI < EE by 3-9% in those who didn't want to lose weight	-
Høidrup *et al.*, 2002	348 adults Denmark	7 day record Diet history	Estimated BMR x PAL from questions on PA	Diet Record: EI < EE by 16% (men), 19% (women) Diet history: EI < EE by 18% (men), 22 % (women)	-
Milne *et al.*, 1991	40 adult men	Two 7 day WR	Estimated BMR x PAL from 7 day activity diaries	EI < EE by 2% (1st record), by 7% (2nd record)	-
Horner *et al.*, 2002	102 women 50-79 years	FFQ	Measured BMR and accelorometer	EI < EE by 21%	-
Meirelles *et al.*, 2001	60 female adolescents (Vegetarian /Omnivore)	FFQ 3 day record	Estimated BMR and PAL from questions on activity	Vegetarian: EI < EE by 29% Omnivores: EI < EE by 34%	-

Abbreviations: hr = hour; WR = weighed record; DLW = doubly labelled water; EI = energy intake; EE = energy expenditure; TEE = total energy expenditure; URs = underreporters; ORs = Overreporters; RMR = resting metabolic rate; BMR = basal metabolic rate; REE = resting energy expenditure; PA = physical activity; PAL = physical activity level; - = not analysed.

Studies using indirect calorimetry

In the studies using indirect calorimetry, energy intakes were measured during a free living period while expenditure was measured over 24 hours in a metabolic setting. It is very likely that energy expenditure in this environment is much less than usual. Lindroos *et al.*, (1999) found a 1% difference between usual energy intakes and expenditure but acknowledged that expenditure was significantly higher during usual activities. Visser *et al.*, (1995) reported a greater difference (12%) between usual energy intakes and expenditure in a respiration chamber while Drougas *et al.*, (1992) found a 206kcal/day discrepancy between energy intakes over 7 days and one 24 hour measurement of EE. The prevalence of underreporting (EI less than 80% of resting energy expenditure) was 37% in a study of young adults (Asbeck *et al.*, 2002).

Studies using measures of physical activity

Five of the studies measured expenditure using activity diaries and four reported that energy intake was underestimated by between 2% and 24% (Arroll *et al.*, 1991; Gilliat-Wimberley *et al.*, 2001; Sánchez-Castillo *et al.*, 2001; Milne *et al.*, 1991). In addition, Körtzinger *et al.*, (1997) found that 48% of normal weight adults were underreporters when EI from a 7 day record and a diet history were compared to EE based on an activity diary. A total of six studies estimated EE from questions on usual physical activity and reported that EI was underestimated by between 1% and 24%. In the three studies that measured activity using accelerometers, energy intake was underreported by between 16% and 21% (Goris & Westerterp, 1999; Goris *et al.*, 2001b; Horner *et al.*, 2002). Rothenberg *et al.*, (1998) measured activity by heart rate monitoring in 12 older adults and found that 3 (25%) underreported EI and 2 (17%) overreported EI in comparison to estimated EE. Johnson *et al.*, (1994) used a predictive equation to estimate EE. The equation had been derived from DLW measures of EE and showed that 12% of men and 24% of women were underreporters.

1.2.5 Goldberg cut-offs for EI/BMR

Since their initial publication in 1991 (Goldberg *et al.*, 1991), these cut-offs have been widely used to identify a bias towards underestimated energy intake in a study sample and to identify individual energy underreporters within the study sample. The 31 studies listed in Table 1.3 have used the cut-offs to identify individual energy underreporters. The prevalence of underreporting in these studies vary widely from less

than 1% (Haraldsdöttir & Sandstrom, 1994) to 61% (Kloppenberg *et al.*, 2002). The studies are ordered according to dietary assessment method.

The EI/BMR cut-off, proposed by Goldberg *et al.*, (1991) to identify individual underreporters with a food record for one day only, was low at 0.92 (95% confidence limit) as energy intake on one day may not represent usual intake. Nonetheless, 31% of the participants in NHANES II (National Health and Nutrition Survey) reported energy intakes below this cut-off (Klesges *et al.*, 1995). The prevalence of underreporting in NHANES III was lower at 23% (EI/BMR < 0.9), which was attributed to improved use of the 24 hour recall method and to the inclusion of weekend days (Briefel *et al.*, 1997). Most of the 24 hour recall studies used the correct cut-off for identifying underreporters.

Food frequency questionnaires and dietary histories normally assess food intake over a given period e.g. one month to a year. Most investigators chose the cut-off of 1.14, calculated by Goldberg *et al.*, (1991), for energy intakes representing 28 days of more. The prevalence of underreporting in these studies ranged from 12% to 28%. Two of the diet history studies in Table 1.3 chose higher cut-offs (1.27, 1.35) and categorised 42% to 57% of their sample as underreporters (Mattison *et al.*, 2001; Mensink *et al.*, 2001).

All of the other studies in Table 1.3 collected food intakes by records, weighed and unweighed, over 3 to 11 days. The cut-offs chosen varied between studies with many using 1.27 and 1.35 to identify individual underreporters. These values are not derived from the Goldberg equation and are not currently considered valid cut-offs for identifying individual underreporters unless calculated from the equation using study specific PAL values (Black, 2000b). On the other hand, many studies chose more relevant cut-offs for identifying individual underreporters (1.06 to 1.1) reporting prevalences of 11% to 39%. Only one study (Haraldsdöttir & Sandstrom, 1994) recalculated the Goldberg cut-offs using study-specific PALs and reported that 6% of their population were underreporters compared to less than 1% based on a cut-off using a PAL of 1.55.

The prevalence of overreporting was calculated in three studies using cut-offs for EI/BMR of 1.82 to 2.5. In a study of 43year olds in the UK who completed a 7-day record, EI/BMR was greater than 2.0 in 4.3% and greater than 2.5 in 0.3% (Price *et al.*, 1997). In 70 year olds from Sweden, EI/BMR was above 2.1 in 8% of men and above

Table 1.3 Prevalence of Underreporting in Dietary Surveys using the Goldberg cut-offs for EI/BMR.

Author	Sample	EI Method	Cut-off	% Under-reporters	% Over - reporters	Mean EI/BMR
Briefel *et al.*, 1995; 1997	7769 Adults NHANES III	24 hr recall	EI/BMR < 0.9	23% (All) 18% (M) 28% (F)	Not calculated	1.36 (All) 1.46 (M) 1.36 (F)
Krebs-Smith *et al.*,2000	8334 US Adults CSFII (1994-1996)	Two 24 hr recalls	EI/BMR <0.80	15% (All)	Not calculated	Not presented
Heywood *et al.*, 1983	1983 adults Australia	24 hr recall	EI/BMR <0.90 EI/BMR <0.68	18% (All) 12% (M) 24% (F) 7.5% (All) 4% (M) 11% (F)	Not calculated	1.39 (All) 1.51 (M) 1.28 (F)
Johansson *et al.*, 2001	193 adults Sweden	Ten 24 hr recalls	EI/BMR <1.2	44% (M) 47% (F)	Not calculated	1.25 (M) 1.21 (F)
Klesges *et al.*, 1995	11,663 participants NHANES II	24 hr recall	EI/BMR <0.92 EI/BMR >0.92<1.20	31% (All) 23% (All)	Not calculated	Not presented
Gnardellis *et al.*,1998	9262 adults Greece, EPIC	FFQ	EI/BMR <1.14	12 % (All) 13.5% (M) 10.5% (F)	Not calculated	1.67 (All) 1.62(M) 1.72(F)
Trichopoulou *et al.*,2001	27953 adults Greece	FFQ	EI/BMR <1.14	28% (All)	Not calculated	Not reported
Johansson *et al.*, 1998	3020 Adults Norway	FFQ	EI/BMR <1.14 EI/BMR <1.35	23 % (All) 20% (M) 25% (F) 42 % (All) 38% (M) 45% (F)	EI/BMR >/= 2.4 6 % (All) 7% (M) 5% (F)	1.53 (All) 1.58(M) 1.48(F)
Brunner *et al.*, 2001	860 adults Whitehall II (UK)	FFQ	EI/BMR <1.2	35 % (All) 32% (M) 35% (F)	Not calculated	Not presented
Kruger *et al.*,2002	1040 women, South Africa	FFQ	EI/BMR <1.2	44%	Not calculated	Not presented
Smith *et al.*, 1994	512 adults Australia	FFQ	EI/BMR <1.14	28.5% (All) 26% (M) 30% (F)	None	1.48 (All)
Rothenburg *et al.*, 1997	809 70 year olds Sweden	Diet history	EI/BMR <1.20 EI/BMR <1.52	22% (M) 28% (F) 56% (M) 57% (F)	EI/BMR > 2.1 (8% M) EI/BMR >1.82 (18% F)	
Stallone *et al.*,1997	865 adults (Whitehall II)	7 day record	EI/BMR < 1.20	33% (All) 32% (M) 35% (F)	Not calculated	1.37 (All)

Table 1.3 (cont/d) Prevalence of Underreporting in Dietary Surveys using the Goldberg cut-offs for EI/BMR.

Author	Sample	EI Method	Cut-off	% Under-reporters	% Over-reporters	Mean EI/BMR
Price *et al.*, 1997	1898 43 yr olds (UK)	7 day record	EI/BMR < 1.10	20.6% (All) 18.5% (M) 22.7% (F)	4.3% EI/BMR > 2.0 0.3% EI/BMR > 2.5	1.37 (All) 1.39 (M) 1.36 (F)
Becker *et al.*, 1999	2000 adults (Sweden)	7 day record	EI/BMR < 1.10 EI/BMR < 1.35	26% 53%	Not calculated	Not presented
De Castro *et al.*, 2002	56 adults (type1DM) 28 controls	4 X 7 day records over 1 yr	EI/BMR < 1.10	12% (All) 14% (DM) 11% (controls)	Not calculated	1.42 (All)
Drummond *et al.*, 1998	95 adults UK	7 day record	EI/BMR < 1.10	17% (All) 12% (M) 21% (F)	Not calculated	Not presented
Kloppenburg *et al.*, 2002	38 Renal disease patients	4 X 7 day records	EI/BMR < 1.27	61% (All)	Not calculated	1.21 (All)
Toellar *et al.*, 1997	2868 adults Multi centre IDDM study	3 day record	EI/BMR < 1..06	11%	Not calculated	1.21 (All)
Crawley *et al.*, 1993	1610 16-17 yr UK	4 day record	EI/BMR < 1.35 (excl, dieters) EI/BMR < 1.06 (excl, dieters)	20% (M) 17% (F) 6%(M) 6%(F)	Not calculated	1.56 (M) 1.48 (F)
Fogelholm *et al.*, 1996	1317 adults (1982) 1429 adults (1992) Finland	3 day record	EI/BMR < 1.28	1982: 26% (M) 34% (F) 1992: 42% (M) 47% (F)	Not calculated	Not presented
Lührmann *et al.*, 2001	343 older adults Germany	3 day record	EI/BMR < 1.073	16% (M) 8% (F)	Not calculated	1.53 (M) 1.62 (F)
Mensink *et al.*, 2001	148 adults Germany	3 day record Dishes 98 diet history	EI/BMR < 1.27 EI/BMR < 1.27	31% (M) 31% (F) 32% (M) 51% (F)	Not calculated Not calculated	Not presented Not presented
Lafay *et al.*, 1997	1030 > 15 yrs France	3 day record	EI/BMR < 1.05	16% (M) 16% (F)		1.41 (M) 1.44 (F)
Mattison *et al.*, 2001	3240 men 7055 women (Sweden)	Diet History	EI/BMR < 1.35	42% (M) 47% (F)	Not calculated	Not presented

Table 1.3 (cont/d) Prevalence of Underreporting in Dietary Surveys using the Goldberg cut-offs for EI/BMR.

Author	Sample	EI Method	Cut-off	% Under-reporters	% Over-reporters	Mean EI/BMR
Haraldsdöttir & Sandstrom 1994	70 Danish adults (20 – 30 yrs)	7 day WR	1. EI/BMR PAL= 1.55 2. EI/BMR cut-offs using study-specific PAL	1. <1% UR 2. 6% UR	Not calculated	Not presented
Pryer *et al.*, 1997	2168 British adults (16 – 64 yrs) DNSBA	7 day WR	EI/BMR < 1.20	38% (All) 29% (M) 46% (F)		
Summerbell *et al.*, 1996	220 subjects (adolescents, working age, middle aged, elderly)	7 day WR	EI/BMR < 1.10	All 15% 4% (M) 20% (F) Adolescents 18% 0% (M) 29% (F) Working age 8% 7% (M) 10%(F) Middle aged 30% 17% (M) 32% (F) Elderly 11% 0% (M) 16% (F)	Not calculated	1.21 – 1.61
Sánchez – Castillo *et al.*, 2001	46 Mexican women	7 day WR	EI/BMR < 1.14 (BMR measured) EI/BMR < 1.10 (BMR estimated	39% 7%	Not calculated	1.27 urban 1.57 rural
Cox & Mela 2000	89 adults Australia	4 day WR	EI/BMR < 1.06	16% 18% of obese 12% of lean	Not calculated	1.63 (lean) 1.48 (obese)
Heath *et al.*, 2000	49 adult women	11 day WR	EI/BMR < 0.94 (99.7% CI)	16%	Not calculated	Not presented

Abbreviations: hr = hour; BMR = basal metabolic rate; EI = energy intake; M = male; F = female; CSFII = Continuing Survey of Food Intakes by Individuals; NHANES = National Health and Nutrition Examination Survey; FFQ = food frequency questionnaire; EPIC = European Prospective Investigation into Cancer and Nutrition; WR = weighed record; UR = underreporter; PAL = physical activity level yr = year; DM = diabetes mellitus; IDDM = insulin dependent diabetes mellitus; excl = excluding.

1.82 in 18% of women (Rothenberg *et al.*, 1997). Using a study-specific PAL allows overreporters to be identified when the upper 95% confidence limit of agreement between EI/BMR and PAL is calculated (Black, 2000b).

Ferrari *et al.*, (2002) reported on the validity of data from 24 hour recalls in 35,955 adults in 10 countries from the European Prospective Investigation into Cancer and Nutrition (EPIC). The prevalence of underreporting (EI/BMR < 0.88) and overreporting (EI/BMR > 2.72) was presented for men (8 countries) and for women (all 10 countries). Underreporting was highest in Greece at 20% of men and 33% of women. In the UK, 12% of men and 15% of women were underreporters. The lowest prevalence of underreporting for men was in Spain (5%) and in France (7%) for women. In all countries, the prevalence was higher among women. A much smaller proportion of subjects overreported their energy intake (1-3% of men, 1-2% of women).

1.3 Characteristics of Underreporters

Many authors have characterised the underreporters in their study sample to provide a better understanding of energy underreporting. Table 1.4 outlines the findings of 27 of these studies. It is difficult to compare each of the studies directly as there are variations in sample size, in the methods used to identify underreporters and in the prevalence of underreporting between the studies. Moreover, many of the characteristics of underreporters are likely to be interdependent.

Body weight

The most consistent finding is that overweight and obese subjects are most likely to underreport their food intake with 23 of the 27 studies reporting this finding. Indeed, body weight status is the variable most frequently addressed in studies characterising underreporters. The first published study comparing energy intakes to energy expenditure, measured using doubly labelled water, showed that obese women underreported their energy intake by 35% (Prentice *et al.*, 1986). The measures of energy expenditure in that study dismissed the previously held idea that obese women reported low energy intakes due to low energy requirements. These finding have subsequently been replicated in similar studies (Lichtman *et al.*, 1992; Johnson *et al.*, 1994). Studies have presented the significant association between body weight and energy underreporting in different ways. The prevalence of underreporting according to body mass index (BMI) categories showed that those overweight or obese were more

Table 1.4 Characteristics of Energy Underreporters.

Author	Johansson *et al.*, 1998	Rothenberg *et al.*, 1997	Fogelholm *et al.*, 1996	Bandini *et al.*, 1997	Heitmann 1993	Gnardellis *et al.*, 1998	Tomoyasu *et al.*, 2000	Braam *et al.*, 1998	Krebs-Smith *et al.*, 2000
Sample	3020 adults Norway	809 (70yrs) Sweden	1317 adults (1982) & 1429 (1992) Finland	109 girls (8-12 years) USA	323 Adults Denmark	9262 Adults Greece	64 Older African Americans	4546 Adults Netherlands	8334 Adults USA
Diet	FFQ	Diet History	3 day record	7 day record	Diet History	FFQ	3 day record	FFQ	2x24hr recall
UR	EI/BMR < 1.35	EI/BMR < 1.20	EI/BMR < 1.28	EI< EE (DLW)	Urinary N > Dietary N	EI/BMR < 1.14	EE < EE	See analysis below	EI/BMR < 0.8
Weight	Overweight Obese	Overweight Obese	Overweight Obese	NS	Overweight	Overweight Obese	NS	Overweight Obese	Overweight Obese
Sex	Women	Women	Women	N/A	NS	Men	NS	Separate analysis	Women
Smoking	Non-smokers	-	-	-	NS	-	-	Current (Men)	NS
Age	Older	N/A	-	Older	NS	Older	NS	Older (Men)	Older
Education	More educated	-	-	-	NS	Illiterate	NS	High (Men)	Less educated
Physical Act	Less PA	-	-	-	NS	-	Low fitness	NS	Less exercise
Social Class	-	-	-	Family income NS	NS	-	Income NS	-	Lower income
Restrained	-	-	-	-	-	-	-	-	-
Others	Desire for weight change	-	-	-	(1)Wt diff of +/- 3kg in 5yrs. (2) Hx slimming /wt problem (3) Unstable wt since 25yr	-	-	(1) Currently trying to lose wt. (2) Dieting frequency in last yr	(1) Non-hispanic Black

Table 1.4 (cont/d) Characteristics of Energy Underreporters.

Author	Hirvonen *et al.*, 1997	Stallone *et al.*, 1997	Lührmann *et al.*, 2001	Price *et al.*, 1997	Pryer *et al.*, 1997	Hulshof *et al.*, 1995	Johnson *et al.*, 1994	Ballard-Barbash *et al*, 1996	Klesges *et al.*, 1995
Sample	3209 adults (1982 & '92) Finland	865 adults UK	343 older adults Germany	1898 adults (43yrs) UK	1856 adults UK	69 Turkish Immigrants Netherlands	137 Older Adults USA	1854 Women USA	11,663 NHANES II (1985-1996)
Diet	3 day record	7 day record	3 day record	7 day record	7 day WR	2 x 24h recall	3 day record	4 x 24 hr recall	24 hr recall
UR	EI/BMR < 1.27	EI/BMR < 1.2	EI/BMR < 1.073	EI/BMR < 1.1	EI/BMR < 1.2	Quintiles of EI/BMR	EI < EE	EI/BMR < 1.06	EI/BMR < 0.92
Weight	Overweight Obese	Overweight Obese	Overweight Obese	Overweight Obese	Overweight Obese	Overweight Obese	High % body fat	Overweight Obese	Overweight
Sex	Women	NS	Men	Women	Women	NS	Women	NA	Obese
Smoking	-	-	-	NS	Smokers	-	-	NS	Women
Age	Older	Older (Women)	N/A	N/A	NS	Older related to BMI	-	NS	Younger (Women)
Education	High education	-	Lower education	Lower (Women)	-	-	-	Lower	Lower
Physical Act	-	-	-	NS	-	-	-	NS	-
Social Class	-	Low grade of employment	-	Parents non manual	Manual (Women)	NS	-	-	-
Restrained	-	-	-	-	-	-	-	-	-
Others	(1) more URs in one region of country	-	(1) URs wanted to lose weight	(1) EI/BMR < 1.1 in 1982 diary	(1) Non drinkers (2) Not married(Men (3)Black or Asian (Men) (4) Scotland (Men)	-	Only measured physiological variables	(1) Poorer health status	-

Table 1.4 (cont/d) Characteristics of Energy Underreporters.

Author	Taren *et al.*, 1999	Lafay *et al.*, 1997	Johannsson *et al.*, 2001	Voss *et al.*, 1998	Briefel *et al.*, 1997	Smith *et al.*, 1994	Asbeck *et al.*, 2002	Høidrup *et al.*, 2002	Horner *et al.*, 2002
Sample	37 Women USA	1030 adults France	193 Adults Sweden	5218 Adults Germany	7769 Adults NHANES III	512 Adults Australia	83 Adults Germany	348 Adults Germany	102 Women (5-79yrs)
Diet	3 day record	3 day record	10 x 24 hr recalls	FFQ	24 hr recall	FFQ	7 day record	EI < EE	FFQ
UR	EE < TEE	EI/BMR < 1.05	EI/BMR < 1.2	EI/BMR quintiles	EI/BMR < 0.9	EI/BMR < 1.14	EI < est TEE by 20%	Diet history 7 day record	EI < est TEE
Weight	High % body fat	Obese	Heavier	Overweight Obese	Overweight	Overweight	NS	Overweight Obese	NS
Sex	-	NS	NS	NS	Women	Women	NS	NS	NA
Smoking	-	-	Smokers	-	Non smokers	-	-	-	-
Age	Older	NS	Older	NS	Older	NS	NS	Older (Men)	Younger
Education	-	-	NS	NS	Low Education	NS	-	-	NS
Physical Act	-	-	-	Low	Low Activity	NS	-	-	NS
Social Class	-	High socio - economic	NS	NS	Poverty	-	-	-	-
Restrained	-	High	-	-	-	-	High	-	-
Others	(1) High social desirability	(1) Having dieted once	-		(1) Non-Hispanic Black (Men) (2) Trying to lose weight (3) Weekend day	-	-	-	(1) High social desirability (2) perceived thiness

Abbreviations: NHANES = National Health and Nutrition Examination Survey; yr = year; hr = hour; FFQ = food frequency questionnaire; WR = weighed record; DLW = doubly labelled water; N = nitrogen; EI = energy intake; EE = energy expenditure; TEE = total energy expenditure; est = estimated; N/A = non applicable; NS = non significant; Urs = underreporters; wt = weight; Hx = history; - = not analysed.

likely to underreport energy intake (Gnardellis *et al.*, 1998: Ortega *et al.*, 1996; Bandini *et al.*, 1990). In a study of over 1800 women in USA, Ballard Barbash *et al.*, (1996) found that 71% of those with a BMI > 27 were underreporters. This has been supported by the significant decrease in EI/BMR as BMI increases (Kruger *et al.*, 2002; Briefel *et al.*, 1997; Heerstrass *et al.*, 1998; Braam *et al.*, 1998). Others have shown that body weight increases as the ratio of EI/BMR or the ratio of EI to EE decreases (Johannson *et al.*, 1998; Lührmann *et al.*, 2001; Körtzinger *et al.*, 1997; Krebs-Smith *et al.*, 2000; Pryer *et al.*, 1997; Hulshof *et al.*, 1995). Many studies have also identified overweight and obese as independent predictors of underreporting using regression analysis (Johannson *et al.*, 1998; Gnardellis *et al.*, 1998; Braam *et al.*, 1998; Klesges *et al.*, 1995; Lafay *et al.*, 1997).

While it is currently accepted that underreporting is more prevalent in the overweight and obese, underreporting is certainly not confined to this group. Three of the studies in Table 1.4 reported no significant association between underreporting and increasing body weight (Horner *et al.*, 2002; Bandini *et al.*, 1997; Tomoyasu *et al.*, 2000). A further two studies have shown that overweight and normal weight subjects underreported their food intakes to the same extent (Lissner *et al.*, 1989; Lindroos *et al.*, 1993).

Underreporting is also significantly related to dieting. Johannson *et al.*, (1998) reported that a 'desire for weight change' in subjects predicted underreporting. This finding was also reported by Lührmann *et al.*, (2001). Other studies state that a recent history of dieting was either significantly associated with underreporting (Heitmann 1993) or predicted underreporting (Braam *et al.*, 1998; Lafay *et al.*, 1997). Energy intake was also underreported after weight loss in men and women previously obese (Black *et al.*, 1995).

Restrained eating

The relationship between body weight and energy underreporting has been further researched by studies investigating the psychological aspects of eating behaviour including restrained eating, perception of body weight status and social desirability. Dietary restraint is defined as 'the tendency to control food intake consciously in order to prevent weight gain or to promote weight loss' (Tuschl, 1990). There are several questionnaires designed to identify restrained eating including the Dutch Eating

Behaviour Questionnaire (van Strien *et al.*, 1986). Restrained eating is associated with energy underreporting with higher levels of underreporting in restrained eaters compared to unrestrained eaters (Poppitt *et al.*, 1998; Black *et al.*, 1995; Bingham *et al.*, 1995; Lafay *et al.*, 1997; Asbeck *et al.*, 2002; Bathalon *et al.*, 2000). In a group of normal weight subjects, Asbeck *et al.*, (2002) reported that body weight and body mass index did not differ between normal reporters and underreporters but that higher dietary restraint was associated with higher underreporting in both men and women. Furthermore, dietary disinhibition described as 'the tendency to overeat as a consequence of several environmental or emotional cues' was associated with underreporting in men but not in women suggesting that psychological aspects of eating behaviour have a different influence on men and women (Asbeck *et al.*, 2002). A more general psychological variable, social desirability, is also associated with energy underreporting. This is the tendency to provide the most socially desirable response regardless of whether it is true or not e.g. a socially desirable response in reporting food intakes may be lower energy, fat and sugar intakes (Taren *et al.*, 1999). Indeed high social desirability scores were associated with low energy and fat intakes in women and, to a lesser extent, in men (Herbert *et al.*, 1995) while there was no relationship between fruit and vegetable intakes and social desirability in a study of women only (Herbert at al., 2001). The relationship between social desirability and underreporting was also shown in a further study of 80 women by Herbert *et al.*, (2002) where energy intakes from three dietary assessment methods were underestimated to the greatest extent by those with the highest social desirability scores. Herbert *et al.*, (2002) also measured social approval - the tendency to seek a positive response or to cooperate in a testing situation, which is less focussed on defensiveness than social desirability. Social approval was related to an overestimation of food intake in men only (Herbert *et al.*, 2002). In another study of 37 women, Taren *et al.*, (1999) showed that both social desirability and dissatisfaction with body weight were associated with energy underreporting

Sex

A total of eleven of the 27 studies in Table 1.4 reported that women were more likely to underreport their foods intakes than men, while only two studies found men more likely to underreport (Gnardellis *et al.*, 1998; Lührmann *et al.*, 2001). Of the other 14 studies, four included women or girls only, one analysed the predictors of underreporting for men and women separately and the other nine found no significant difference in

underreporting between men and women. Considering the association between underreporting and a range of weight-related variables: restrained eating, dieting, social desirability and desire to lose weight, it is not surprising that women are frequently more likely to underreport their food intake than men.

Age

In 14 of the 27 studies in Table 1.4, underreporting differed significantly with age. The majority of these differences showed that underreporting increased with age for both men and women. NHANES II was an exception where being young independently predicted underreporting (Klesges *et al.*, 1995). Most of the differences noted in the table are independent of other factors associated with increasing age e.g. weight gain. Hulshof *et al.*, (1995) did show that the higher prevalence of underreporting with age was related to being overweight or obese. Of the other 13 studies, six found no difference in energy underreporting with age while four included subjects of either the same age or the same age group. Two of the studies didn't report on age and Horner *et al.*, (2002) found that young post menopausal women were more likely to underreport than their older counterparts. There is some evidence that adolescence influences underreporting as Livingstone *et al.*, (1992) showed little or no underreporting in young children (3 to 9 years) compared to children aged 12 years and above.

Smoking

The relationship between smoking and underreporting is unclear. Only nine of the 27 studies in Table 1.4 addressed the independent association between smoking and underreporting with conflicting findings. There were no differences in smoking status in underreporters in four of the studies. In three studies, current smokers were more likely to underreport (Pryer *et al.*, 1997; Johannson *et al.*, 2001; Braam *et al.*, 1998) and in two studies non-smokers were more likely to underreport (Briefel *et al.*, 1997; Johannson *et al.*, 1998). The prevalence of smoking in subgroups of the population is likely to be relevant as smoking may be associated with weight control.

Education

Education was addressed in 16 of the studies in Table 1.4. Low education was associated with underreporting in 7 studies while underreporters were more likely to be better educated in three studies. A total of six studies showed no significant difference in educational attainment among underreporters. The finding of a lower education in

underreporters is not surprising considering that most dietary assessment methods rely on literacy and numerical skills.

Physical Activity

A total of 11 studies in Table 1.4 measured physical activity of which six found that underreporters had 'low activity', 'low fitness' or 'low exercise'. The other 5 studies found no significant association between physical activity and underreporting. These findings contrast with evidence that energy underreporting is highest in those with high energy expenditure (Lissner *et al.*, 1989; Visser *et al.*, 1995). It is possible that physical activity in the studies in Table 1.4 refer specifically to exercise rather than overall energy expenditure.

Social Class

Social class, employment or income was measured in 12 of the studies listed in Table 1.4. Of these studies, 6 reported no association between social class and underreporting. The other six studies provide inconsistent findings. Underreporting was related to high socio-economic class in French adults (Lafay *et al.*, 1997) while in a UK study, underreporting was more prevalent in manual workers (Pryer *et al.*, 1997). In the Whitehall II study, more underreporters were in a low employment grade (Stallone *et al.*, 1997). In two US studies, underreporting was related to low income (Tomoyasu *et al.*, 2000) and poverty (Briefel *et al.*, 1997). These results are difficult to interpret as different measures of social class are used across the studies. In addition, the social class of the population that each study represents will vary.

1.4 Underreporting of Foods and Nutrients

While comparing energy intake to energy expenditure or energy requirements identifies energy underreporting, it does not identify which foods or nutrients are underreported. If all foods were underreported equally, food and nutrient intakes could be simply adjusted to account for underreporting. This does not happen, however, with evidence of differential underreporting of foods and nutrients in dietary surveys. These differences will be discussed in this section. The main obstacle in identifying the extent, if any, to which individual nutrients are underreported is the absence of biomarkers against which nutrient intakes can be measured. Urinary nitrogen, and to a lesser extent urinary potassium, have been used to measure the validity of protein and potassium intakes as discussed earlier. There are, however, no biomarkers for total fat,

carbohydrate or alcohol intakes. In a recent review, Arab & Akbar (2002) acknowledged that there is no good biomarker for total fat and, that while adipose tissue fatty acids can indicate dietary intake over one or two years, this time frame is frequently different to that covered by dietary assessment.

1.4.1 Macronutrients

The absolute intakes of all macronutrients are likely to be lower in underreporters than in others as underreporters have lower food intakes in general. Most authors have therefore expressed macronutrient intakes as percentages of total or food energy in determining if there is differential reporting of macronutrients among underreporters. Table 1.5 outlines the findings of 15 studies that have addressed energy underreporting and macronutrient intakes. Most of the studies have compared nutrient intakes between underreporters and acceptable reporters after identifying underreporters by EI/BMR cut-offs or by expressing energy intake as a percentage of energy expenditure. One study compared nutrient intakes from observed and reported intakes (Poppitt *et al.*, 1998) and another compared protein intake to urinary nitrogen excretion (Heitmann & Lissner, 1995). Some studies compared those in the lower EI/BMR category to those in a higher category for EI/BMR (Becker *et al.*, 1999; Hulshof *et al.*, 1995; Voss *et al.*, 1998; Johansson *et al.*, 2001; Rothenberg *et al.*, 1997).

There are no absolutely consistent findings between the studies. The most consistent finding however, is a higher protein intake in underreporters compared to acceptable reporters in the majority of studies, suggesting valid reporting or over reporting of protein intakes relative to the other macronutrients (Lührmann *et al.*, 2000; Körtzinger *et al.*, 1997; Pryer *et al.*, 1997; Price *et al.*, 1997; Briefel *et al.*, 1997; Heitmann & Lissner, 1995; Becker *et al.*, 1999; Lafay *et al.*, 1997; Voss *et al.*, 1998; Rothenberg *et al.*, 1997; Johansson *et al.*, 2001). Studies comparing protein intakes to urinary nitrogen excretion found, however, that protein intakes were also underreported but to a lesser extent than energy intake (Heitmann & Lissner, 1995; Heitmann *et al.*, 2000). Underreporters do not always report higher protein intakes. When food intakes were measured in 50 young adults using both a diet history and a 7 day food record, underreporters had lower protein intakes than others but these differences were only significant with the diet history results (Körtzinger *et al.*, 1997). In addition, when Poppitt *et al.*, (1998) covertly observed food intakes in 33 women over one day, protein intakes were similar to that reported by the women.

Table 1.5 Macronutrient Intakes in Energy Underreporters.

Author	Sample	Diet	UR	% En Fat	% En CHO	% En Prot	% En ROH	Fibre	Analysis
Lührmann *et al.*, 2001	343 Adults Germany	3 day record	EI/BMR < 1.073	NS	NS	Higher	-	NS	URs *vs* Others
Körtzinger *et al.*, 1997	50 Adults	Diet History 7 day record	EI < EE	Lower NS	Higher Higher	Lower NS	NS NS	-	URs *vs* Others
Pryer *et al.*, 1997	1856 Adults UK	7 day WR	EI/BMR < 1.2	NS	Lower Sugar-lower	Higher	Lower (F) NS (M)	-	URs *vs* Others
Price *et al.*, 1997	1898 43y olds, UK	7 day record	EI/BMR < 1.1	Lower	NS	Higher	NS	-	URs *vs* Others
Briefel *et al.*, 1997	7769 Adults USA	24 hr recall	EI/BMR < 0.9	Lower	Higher	Higher	Lower (F) NS (M)	-	URs *vs* Others
Johnasson *et al.*, 1998	3144 Adults Norway	FFQ	EI/BMR < 1.35	Lower	- Sugar-lower	-	NS	-	URs *vs* Others
Poppitt *et al.*, 1998	33 Women USA	Observed & reported	Reported < Observed	NS	Lower Sugar-lower	NS	NS	-	Observed *vs* Reported
Heitmann & Lissner, 1995	323 Adults Denmark	Diet History	EI < EE Protein < Urinary N_2	-	-	Higher	-	-	Intake *vs* Urinary N_2
Becker *et al*, 1999	2000 1-74y Sweden 1212 Adults Ireland	7 day record FFQ	EI/BMR < 1.10 EI/BMR < 1.27	Lower SFA -lower Lower SFA - lower	NS Lower	Higher Higher	- -	- -	URs *vs* Others

Table 1.5 (cont/d) Macronutrient Intakes in Energy Underreporters.

Author	Sample	Diet	UR	% En Fat	% En CHO	% En Prot	% En ROH	Fibre	Analysis
Hulshof *et al.*, 1995	69 Turkish Immigrants	2x24 hr recall	Tertile 1 *vs* 3 EI/BMR	NS	NS	NS	-	-	Tertile 1 *vs* 3 EI/BMR
Asbeck *et al.*, 2002	83 adults Germany	7 day record	EI < EE by 20%	NS	NS	NS	NS	-	URs *vs* Others
Lafay *et al.*, 1997	1030 (>15y) France	3 day record	EI/BMR < 1.05	NS	Lower (non obese only)	Higher	Lower (non obese only)	-	URs *vs* Others
Voss *et al.*, 1998	5218 Adults Germany	FFQ	Quintiles of EI/BMR	Lower	Higher	Higher	Higher	-	Quintiles of EI/BMR
Rothenberg *et al.*, 1997	808 73yrs Sweden	Diet history	3 EI/BMR categories	Lower	NS	Higher	-	-	Quintiles of EI/BMR
Johannason *et al.*, 2001	193 adults Sweden	10 x 24hr recalls	EI/BMR < 1.2	Lower	NS Sugar-lower	Higher	NS	NS	URs *vs* Others

Abbreviations; EI = energy intake; BMR = basal metabolic rate; UR = underreporter; CHO = carbohydrate; Prot = protein; ROH = alcohol; EE = energy expenditure; F = female, M = male; hr = hour; FFQ = food frequency questionnaire; N_2 = nitrogen; SFA = saturated fatty acid; y = year; - = not analysed.

Lower fat intakes are frequently found in underreporters. In the 14 studies listed in Table 1.5 that addressed fat intakes, eight reported significantly lower fat intakes in underreporters or in those in the lowest EI/BMR category. The other six studies reported no difference in fat intakes in those with underreported energy intakes. No study found higher fat intakes in underreporters. In addition, significantly lower saturated fat intakes were found in underreporters from a sample of 1212 Irish adults who completed a food frequency questionnaire (FFQ) (Becker *et al.*, 1999). Poppitt *et al.*, (1998) found no differences between observed and reported fat intakes in either obese or non-obese women. In a study of 30 obese men where energy intakes were 37% lower than energy expenditure, there was evidence of selective underreporting of fat at main meals only (Goris *et al.*, 2000). As fat is energy dense, providing 9 kcals per gram, underreported fat intakes will have a greater impact on the degree of energy underreporting than either protein or carbohydrate.

The evidence that carbohydrate is underreported in dietary studies is conflicting. With reference to the 15 studies listed in Table 1.5, four report significantly lower carbohydrate intakes in underreporters or in those in the lower EI/BMR categories (Pryer *et al.*, 1997; Poppitt *et al.*, 1998; Becker *et al.*, 1999; Lafay *et al.*, 1997). On the other hand, three studies found higher intakes of carbohydrate among underreporters (Körtzinger *et al.*, 1997; Briefel *et al.*, 1997; Voss *et al.*, 1998). In addition, a further seven studies reported no significant difference in total carbohydrate intakes between underreporters and others (Johannson *et al.*, 2001; Rothenberg *et al.*, 1997; Asbeck *et al.*, 2002; Hulshof *et al.*, 1995; Johannson *et al.*, 1998; Price *et al.*, 1997; Lührmann *et al.*, 2001). Total carbohydrate refers to a diverse group of compounds: simple sugars, short chain carbohydrates and the more complex carbohydrates, starch and non-starch polysaccharide (Garrow *et al.*, 2000). All studies that reported on sugar intakes in underreporters found that sugar intakes were significantly lower in underreporters (Pryer *et al.*, 1997; Johansson *et al.*, 1998; 2001; Poppitt *et al.*, 1998). Indeed Poppitt *et al.*, (1998) found that carbohydrate, and specifically sugar intakes, was underreported in the study of observed food intakes in women while protein and fat intakes were well reported. Only two of the studies in Table 1.5 reported on fibre intakes finding no significant differences in intakes in underreporters than in other (Johannson *et al.*, 2001; Lührmann *et al.*, 2001).

It is important to acknowledge the interrelationship between macronutrient intakes when expressed as a percentage of energy intakes, specifically between fat and carbohydrate. The seesaw relationship between fat and carbohydrate is well recognised (Flynn *et al.*, 1996) with a reduction in the % of energy from fat when the % energy from carbohydrate increases and vice versa. This relationship impacts on our understanding of the nutrient intakes in underreporters compared to others. The lower fat intakes in some studies may be related to higher carbohydrate intakes. The converse can also apply with lower carbohydrate intakes due to higher reported fat intakes. Voss *et al.*, (1998) compared mean fat and carbohydrate intakes across quintiles of EI/predicted BMR and found that the fat:carbohydrate ratio increased with increasing EI/BMR.

A total of 10 of the studies in Table 1.5 reported on alcohol intakes in underreporters with no significant differences between underreporters and others in five of the studies (Johannson *et al.*, 1998; 2001; Körtzinger *et al.*, 1997; Price *et al.*, 1997; Asbeck *et al.*, 2002). In the other five studies, alcohol intake was lower in obese underreporters only (Lafay *et al.*, 1997), in women only (Pryer *et al.*, 1997; Poppitt *et al.*, 1998; Briefel *et al.*, 1997) or higher in the highest quintile of EI/BMR (Voss *et al.*, 1998). It has been suggested that alcoholic drinks are not perceived as foods and thus neither consciously or unconsciously, undereaten or underreported (Lührmann *et al.*, 2001). On the other hand, Livingstone *et al.*, (1990b) suggested that self-reported alcohol intake was particularly prone to underestimation.

1.4.2 Micronutrients

Some investigators have specifically examined differences in micronutrient intakes between underreporters and others and found that absolute intakes of micronutrients were lower in underreporters but, when intakes were expressed per MJ of energy intake, micronutrient intakes were frequently significantly higher in underreporters than others. This suggests that the diets of underreporters are more micronutrient dense than those of acceptable reporters. The following are examples of these findings. Price *et al.*, (1997) showed that underreporters had significantly lower intakes of the three nutrients examined (calcium, iron and vitamin C) than others, but significantly higher intakes of these nutrients when expressed as nutrient densities (g/10MJ). Lührmann *et al.*, (2001) reported lower absolute intakes of six micronutrients in older adults identified as underreporters (vitamin A, vitamin E, vitamin C, Beta carotene (men only), calcium and

iron). There were no differences in these 6 nutrients between underreporters and others when expressed as nutrient densities. In NHANES III, underreporters (EI/BMR < 0.9) had significantly lower intakes of the three nutrients examined: iron, calcium and vitamin A, than adequate reporters. Nutrient densities were not calculated (Briefel *et al.*, 1997). In two studies by the same author (Johannson *et al.*, 1998; 2001), micronutrient densities were only reported. In the first study, only vitamin C intakes in women (mg/MJ) were significantly higher in the lowest EI/BMR category (Johannson *et al.*, 1998). In the second study of 193 adults who completed ten 24 hour recalls over one year, nutrient densities for vitamin C, vitamin D, vitamin E, Beta Carotene and calcium did not differ between EI/BMR categories. These results were presented for men and women together (Johannson *et al.*, 2001). Pryer *et al.*, (1997) examined the differences in a wider variety of micronutrients between underreporters and others from the Dietary and Nutritional Survey of British Adults (DNSBA) and found that the mean daily intake of nine minerals and 12 vitamins were significantly lower in underreporters than adequate reporters for both men and women. When micronutrient intakes were expressed according to energy intake, women underreporters had significantly higher intakes of seven of nine minerals (calcium and iodine were the exceptions) and six of 12 vitamins (thiamin, riboflavin, niacin, vitamin B6, folate and pantothenic acid) than adequate reporters. In men, underreporters had higher intakes of four of the nine minerals (sodium, potassium, phosphorous and zinc) and a higher intake of vitamin D than adequate reporters. Similarly, Hirvonen *et al.*, (1997) reported that the absolute intakes of 14 micronutrients were significantly lower in those whose EI/BMR was below 1.27 compared to those with an EI/BMR greater than 1.27 except for thiamin in women. The opposite applied when micronutrients were expressed per MJ of energy intake with significantly higher intakes in women underreporters for 10 of the 14 nutrients and for nine of the 14 nutrients in men.

Our understanding of the impact of underreporting on both macro and micronutrient intake is confounded by the different criteria used to identify underreporters. It is likely that using low cut-offs for EI/BMR will identify subjects with the greatest difference in nutrient intakes. These studies may provide more clear findings but are limited by the fact that the low cut-off for EI/BMR doesn't identify all underreporters (Black *et al.*, 2000a). This highlights the need to improve the methods to identify underreporters in all dietary surveys.

1.4.3 Food Intakes

The differences in both macronutrient intakes and micronutrient intakes between underreporters and valid reporters suggest differences in reported food intakes between the two groups. Table 1.6 outlines 6 studies that have compared food intakes between underreporters and others. In these studies, food intakes are presented as grams per day, % contribution of the food group to energy intake or as grams per MJ of energy. While it isn't possible to directly compare the studies as the food groupings are not identical and the results are presented differently, there are some trends between the studies.

In general, actual food intakes in underreporters are lower than in valid reporters. When food intakes are expressed as grams/MJ or as their % contribution to energy intake, underreporters appear more likely to have higher intakes of energy dilute foods e.g. fruits, vegetables and juices (Rothenberg *et al.*, 1997; Hirvonen *et al.*, 1997), diet drinks (Johannson *et al.*, 1998) and of protein rich foods e.g. fish, meat, poultry (Rothenberg *et al.*, 1997; Hirvonen *et al.*, 1997; Pryer *et al.*, 1997; Johannson *et al.*, 1998; 2001). This supports the general finding of higher protein intakes in underreporters compared to others as discussed earlier. On the other hand, underreporters are more likely to report lower intakes of high fat foods and sugar rich foods, either as grams per day or as the % contribution to energy intake (Lührmann *et al.*, 2001; Rothenberg *et al.*, 1997; Hirvonen *et al.*, 1997; Pryer *et al.*, 1997; Johannson *et al.*, 1998; 2001). This supports the findings of lower fat and lower sugar intakes in underreporters. A comprehensive analysis of food intakes in underreporters is provided by Krebs-Smith *et al.*, (2000) where intakes from 44 food groups are compared between underreporters (EI/BMR < 0.80) and others in a sample of over 8000 US adults. Underreporters were less likely to report all 44 food groups except artificial sweeteners than valid reporters and this difference was statistically significant for 28 of the 44 food groups. In addition, when foods were reported by underreporters, the frequency of reporting was still less, or at best, the same as that reported by valid reporters. Underreporters also reported smaller portions of foods and this difference was significant for 26 of the 44 food groups. The difference in portion sizes between underreporters and others ranged between 0 and 40% (Krebs-Smith *et al.*, 2000).

There is also evidence that underreporters have fewer eating occasions per day (Drummond *et al.*, 1998; Summerbell *et al.*, 1996). In NHANES III, underreporters had less meals and snacks than others (Briefel *et al.*, 1997). In a weighed intake study of 31 adults in Northern Ireland, those with invalid energy intakes reported eating less snacks

Table 1.6 Food Intakes in Energy Underreporters.

Author	Sample	Diet	UR	Food Groups lower in UR	Food Groups higher in UR	Food Groups no difference UR v other
Lührmann *et al.*, 2001	343 Adults Germany	3 day record	EI/BMR < 1.073	Grams/day 1. Bread, buns & cakes 2. Milk, dairy products 3. Meat & Fish (M only) 4. Fruits, vegetables 5. Potatoes, rice, pasta 6. Sugar, sweets 7. Spreads, cooking fats	Grams/day None	Grams/day 1. Alcoholic drinks
Rothenberg *et al.*, 1997	809 Adults Sweden	Diet history	EI/BMR < 1.20	% energy from: 1. Sugar/sweets/soft drinks 2. Spreads, cooking fats	% energy from: 1. Fruit, juice, veg 2. Potatoes, rice,pasta (M only) 3. Meat & Fish	% energy from: 1. Bread, porridge 2. Buns, cakes 3. Milk, yogurt, cheese 4. Alcohol
Hirvonen *et al.*, 1997	1861 Adults Finland	3 day record	EI/BMR < 1.27	Grams/MJ: 1. Fats (cooking, baking, spreads, dressings) 2. Bread (M only)	Grams/MJ: 1. Fish/Meat 2. Potatoes & bread (F) 3. Fruit, berries, veg 4. Cheese	Grams/MJ: 1. Sausages 2. Milk 3. Soft drinks 4. Sweets & ice cream
Pryer *et al.*, 1997	1856 Adults UK	7 day WR	EI/BMR < 1.2	% energy from: 1. Biscuits, pastries, puddings 2. Butter (F only) 3. Sugar, confectionery 4. Alcohol (F only)	% energy from: 1. Bread, pasta, rice 2. Meat, meat products 3. Poultry, Fish 4. Veg, salad, fruit, nuts 5. Fried potatoes	
Johannson *et al.*, 1998	3020 Adults Norway	FFQ	4 categories of EI/BMR	Grams/MJ: 1. Cakes, confectionery 2. Potato Chips 3. Whole Milk 4. Fat 5. Soft drinks	Grams/MJ: 1. Bread, cereals 2. Vegetables, potatoes 3. Meat, Fish 4. Skimmed milk 5. Diet drinks, coffee	Grams/MJ: 1. Alcohol 2. Fruit, berries

than those with higher energy intakes. The difference was not significant (Livingstone *et al.*, 1990a). In the study by Poppitt *et al.*, (1998), where food intakes were covertly measured and simultaneously self-reported, meals were well reported but snacks, particularly high sugar snacks, were significantly underrecorded.

In summary, it appears that all foods are likely to be affected by underreporting as eating occasions and foods are omitted and smaller portion sizes are reported. Additionally, there is evidence that foods high in fat and sugar are less well recorded than energy dilute and protein-rich foods.

1.5 Impact of Underreporting in Dietary Surveys

There are no recommendations on how to deal with underreported energy intakes and the impact of underreporting on the interpretation of food and nutrient intakes. Some investigators have excluded underreporters for different reasons (Drummond *et al.*, 1998; Macdiarmid *et al.*, 1996; Bonifacj *et al.*, 1997) while others have compared results before and after excluding underreporters (Gnardellis *et al.*, 1998; Kruger *et al.*, 2002; Billson *et al.*, 1999; Stallone *et al.*, 1997). Others have argued that excluding underreporters will alter the survey sample, as underreporting is not uniform across all subgroups (Ballard Barbash *et al.*, 1996; Macdiarmid *et al.*, 1996). Much of the discussion on the impact of underreporting has focussed on nutrient intakes and nutrient adequacy with much less discussion on the impact of underreporting on the associations between diet and disease.

In general, energy, macronutrient and micronutrient intakes increase when underreporters are excluded while there are less consistent differences in the proportion of energy from fat, carbohydrate and protein when underreporters are excluded. Gnardellis *et al.*, (1998) reported that all nutrients increased significantly (except alcohol) by approximately 6%, when the 12% of underreporters were excluded. When 44% of the DNSBA sample were excluded (EI/BMR < 1.2 and those dieting and unwell) energy intake increased by 11% in men and 18% in women. The % energy from fat and carbohydrate increased in women while the % energy from protein decreased in women only also (Macdiarmid *et al.*, 1996). There were no significant differences in the proportion of energy from macronutrients when underreporters were excluded in Finnish adults (Fogelholm *et al.*, 1996). The author did report, however,

that the decrease in energy intake between 1982 and 1992 was partly due to the increase in energy underreporting over the same period.

Fewer studies have examined the impact of underreporting on nutritional adequacy. As underreporters have lower intakes of most nutrients, the proportion of the population with low micronutrient intakes decreases, in general, when underreporters are excluded (Haraldsdóttir *et al.*, 1998; Smith *et al.*, 1994). Similarly, due to the lower fat intakes in underreporters, Pryer *et al.*, (1995) showed that the proportion of men and women with fat intakes $\leq$ 35% of food energy decreased when underreporters were excluded.

Excluding underreporters has altered the results of some investigations. In the Whitehall II study, Stallone *et al.*, (1997) found that the significant positive association between employment grade and fat intake no longer existed when those with an EI/BMR < 1.2 were excluded as underreporting was related to both low employment grade and lower fat intakes. The inverse association between eating frequency and BMI has been attributed to underreporting (Summerbell *et al.*, 1996; Drummond *et al.*, 1998; Bellisle *et al.*, 1997) and specifically the omission of snacks eaten. The relationship between dietary fat and carbohydrate and BMI is influenced by the lower fat and sugar intakes in underreporters. Macdiarmid *et al.*, (1998) showed that the positive association between dietary fat and BMI in women was reversed when underreporters were included as obese women had underreported fat intakes.

The increasing prevalence of obesity despite decreasing reported energy intakes and physical activity has also been suggested to be partly attributable to energy underreporting (Heitmann *et al.*, 2000). In addition, the relationship between dietary fat and cancer has been discussed in the context of energy underreporting with no clear conclusions (Wynder *et al.*, 1997).

Despite the impact of underreporting on nutrient intakes, nutrient adequacy and the relationship between food intakes and obesity, there are many arguments against excluding underreporters from dietary survey samples. In the first place, excluding underreporters will reduce the prevalence of overweight and obesity within the sample, which is often the area of study (Macdiarmid *et al.*, 1996). In addition, it will affect the overall characteristics of the sample as women and those who are older are also more likely to underreport their food intakes (Ballard Barbash *et al.*, 1996). Secondly, most

studies have not identified the full extent of energy misreporting as the Goldberg cut-offs, based on PAL of 1.55, may only identify 50% of underreporters (Black, 2000b). Overreporting of energy intakes is also possible but it is infrequently identified (Black 2000a). Clearly, reducing the prevalence of underreporting is the best option in minimising the impact of underreporting on the interpretation of food and nutrient intakes.

1.6 Mechanisms Involved in Underreporting

There is a selection of terms used in the literature to describe unexpectedly low energy intakes in dietary surveys: 'underreporting', 'misreporting', 'low energy reporting' and 'implausible intakes'. Underreporting is the term most frequently used but it implies that the subject has consciously or unconsciously underreported their food intake. In actual fact 'underreporting' is likely due to a combination of undereating, dieting, intentional and unintentional underrecording, poor recall, difficulties in estimating portion size and other dietary assessment errors. While Black (2000a) suggested 'providing diet reports of poor validity' as an alternative phrase, the term 'underreporting' is widely used with the acknowledgement that underreporting is only part of the phenomenon of invalid food records. Each of the above mechanisms that contribute to 'underreporting' will be discussed while recognising that they don't occur in isolation of each other.

1.6.1 Undereating and underrecording

Undereating in food intake studies is a discrepancy in energy intake accompanied by a loss of body weight (Black *et al.*, 1995). Undereating is closely linked with dieting. Underrecording, on the other hand, is the intentional or unintentional omission of foods eaten (Goris *et al.*, 2000) that doesn't involve weight loss and may result in weight gain.

Undereating

Weight is gained when energy intake (EI) is greater than energy expenditure (EE) and weight is lost when EI is less then EE. Black *et al.*, (1995) commented that a randomly selected group of individuals can, on average, be assumed to be weight stable and that while some individuals in a dietary survey will be studied during a period of low food intake and some during a period of high food intake, energy balance (i.e. no difference between EI and EE) can be expected at the group level. There is evidence, however, of negative energy balance (i.e. weight loss) during food intake studies. Some of this evidence is from intervention and metabolic studies that required weight maintenance.

Table 1.7 Changes in body weight during dietary assessment (a) weight maintenance studies.

Author	Sample	Methods	Body Weight Changes	Adjustment of energy intake for weight loss	Comments
Mertz *et al.*, 1991	266 adults	>/=7 day food records to determine energy req for ≥ 45 day intervention studies	Wt measured 5 times/week. Wt stability reached after 2 weeks.	EI adjusted if wt lost during first 2 weeks of intervention	18% underestimation of energy requirements by food records
Pannemans & Westerterp, 1993	17 elderly men 11 elderly women	EI from 4 day record or dietary questionnaire to determine energy req for 3 week intervention	Diet record group: -0.64 +/- 0.50kg/2weeks (-0.32kg/week) Dietary questionnaire: -0.86 +/- 0.90kg/2weeks (-0.43kg/week)	Yes during week 1	Greatest discrepancy between EI and EE in those with highest BMI
Haraldsdöttir & Sandstrom, 1994	87 adults 20-30 years	EI from 7day WR used to predict energy req. during 2-6 week studies	-0.36 +/- 0.45kg (2-6 weeks)	No	17 respondents excluded as not wt stable (lost 0.74kg +/- 1.28kg) EI < EE by 5% (men) and by 8% (women)
deVries *et al.*, 1994	269 adults	EI from 3 day records used to predict energy req. during intervention	Week 1: -0.32+/-0.65kg Week 2: -0.15+/-0.53kg Week 3: -0.05+/-0.91kg	Week 1: EI increased by 10% Week 2: according to wt loss	11 respondents excluded as lost > 2kg after end of week 2. EI < EE by 10%
Raben *et al.*, 1995	48 adults 20-30 years	EI from 7 day record to predict energy requirement for 11 week intervention	Intervention Group: -1.3+/- 0.4kg (11 weeks) (-0.12kg per week) Control Group: 0.0 +/- 0.2kg (11 weeks)		Energy deficit of 0.8MJ/day based on wt loss EI < EE by 5%

Abbreviations; req = required; wt = weight; EI = energy intake; EE = energy expenditure; BMI = body mass index; WR = weighed record; TEE = total energy expenditure; DLW = doubly labelled water; URec = underrecording; UEat = undereating; URing = underreporting; UR = underreporter; OR = overreporter

Table 1.7 (cont/d) Changes in body weight during dietary assessment (b) weight changes during food intake studies.

Author	Sample	Methods	Body Weight Changes	Adjustment of energy intake for weight loss	Comments
Milne *et al.*, 1991	40 men	2 x 7day WR	Week 1: -0.28kg Week 2: -0.26kg	Energy deficit of 10% estimated from wt loss	
Lindroos *et al.*, 1993	64 adults 45 obese 19 non-obese	4 day estimated food record	Obese: -0.6 +/- 1.0kg wt change for non-obese not reported.	Yes, based on 1kg = 7000kcal.	EI in obese increased from 2010kcal to 2550kcal/day after adjustment
Kempen *et al.*, 1995	20 women	8 week food records Diet or diet and exercise intervention	Diet only: -7.1+/-0.9kg (0.89kg/week) Diet and Exercise: -9.1+/-1.1kg (1.14kg/week)	Energy intake calculated as TEE (DLW) minus wt loss	Reported EI less than calcuated EI by 4.5MJ/day (diet group) and 3.1MJ/day (diet and exercise group)
Sawaya *et al.*, 1996	20 women (10 young, 10 old)	7 day WR	Young women: -26g/day (0.18kg/wk) Older women: -34g/day (0.24kg/wk)	No	50% of difference in EI and EE (DLW) due to UEat and 50% due to URec
Lissner *et al.*, 1989	63 women	Observed food intakes over 14 to 63 days	-0.04kg/day (0.28kg/week) most wt loss in obese	Yes, based on regression co-efficient for mean daily wt change	18% difference between reported EI and that observed
Bandini *et al.*, 1990	55 adolescents	14 day food diary TEE by DLW	Obese: +0.37kg+/-0.97 (0.18kg/week) Non-obese: +0.08kg+/-0.69 (0.04kg/week)	Yes, on basis that 1gram adipose tissue is 9.5kcal	EI less than TEE despite wt gain.
Martin *et al.*, 1996	29 women	7day WR TEE by DLW for 13day	-0.23kg+/-0.65 (13days) (-0.12kg/week)	Adjusting EI for wt loss accounted for 24% of difference in EI vs EE	Body wt changes measured over 13 days while EI over 7days
Bratteby *et al.*, 1998	25 boys, 25 girls aged 15y	7 day record TEE by DLW for 7days	Boys:+0.12kg/week Girls: -0.09kg/week	No	82% EI reported (boys) 78% EI reported (girls)

Table 1.7 (cont/d) Changes in body weight during dietary assessment (b) weight changes during food intake studies.

Author	Sample	Methods	Body Weight Changes	Adjustment of energy intake for weight loss	Comments
Taren *et al.*, 1999	37 women	3 day food record TEE over 9days	UR: +0.12+/-0.3kg OR: -0.25+/-0.09kg		
Black *et al.*, 1995	11 successful slimmers	21 day WR TEE by DLW for	-0.80+/-0.82kg (21days) (-0.26kg/week)	No	EI < EE by 27%
Velthuis-te Wierik *et al.*, 1995	24 men: (16 intervention to reduce EI 8 controls)	7 day record pre 10 week intervention.	Intervention: -0.74kg/week Controls: -0.21kg/week	No	TEE by DLW pre intervention in 8 subjects showed that 83% of EI reported.
Warwick & Baines, 1996	11 smokers 10 non-smokers	28 day WR	Smokers: -420g/28day (-0.11kg/week) Non-smokers:-460g/28d (-0.10kg/wk)	Yes, EE calculated as EI + changes in body wt	
Asbeck *et al.*, 2002	83 Adults	7 day food diary	Mean wt pre record: 69.9+/-12.5kg Mean wt post record: 70.3+/-12.5kg	No	All subjects were wt stable during the week as defined by wt change of =+/-0.5kg
Goris *et al.*, 2001a	30 adults	7 day record EE by DLW	Non recording week: +0.62+/-0.74kg Recording week:-0.24+/-0.66kg	Energy cost of wt loss used to calculated % UEat	EI underreported by 19% all of which was URec
Goris *et al.*, 2001b	34 adults (19 exercise intervention, 15 controls)	7 day food record before and after 12 week intervention EE by DLW	Pre intervention week: Exercise:-0.37kgControl:-0.01kg Post Intervention week: Exercise:-0.26kg Control: -0.23kg	Energy cost of wt loss used to calculated % UEat	21% URing pre intervention. 27% URing post intervention of which 15% was UEat
Goris *et al.*, 2000	30 obese men	7 day record EE by DLW	Non-recording week: 0.0 +/-0.1kg Recording week:-1.0 +/-0.1kg	Energy cost of wt loss used to calculated % UEat	37% URing of which 26% was UEat and 12% URec
Goris & Westerterp 1999	24 Dietitians	7 day record EE by DLW	Non-recording week: +0.1+/- 0.6kg Recording week:-0.6 +/- 0.8kg	Energy cost of wt loss used to calculated % UEat	16% URing all of which was UEat

Five of these studies are reviewed in Table 1.7 (Mertz *et al.*, 1991; Pannemans & Westerterp, 1993; Haraldsdöttir & Sandstrom, 1994; deVries *et al.*, 1994; Raben *et al.*, 1995). They all used reported energy intake before the intervention period to predict energy requirements during the intervention. In each of the studies reported energy intake underestimated energy requirements. In addition, respondents lost weight during the intervention period, even after energy intakes were increased to maintain weight stability during a lead in period in three of the studies (Mertz *et al.*, 1991; Pannemans & Westerterp, 1993; deVries *et al.*, 1994).

Table 1.7 also reviews 17 further studies that measured changes in body weight when food intakes were recorded. There was a clear tendency towards weight loss in the majority of the studies, with 12 of the studies in adults reporting a mean weight loss of 0.1 to 1.0kg/week (Milne *et al.*, 1991; Lindross *et al.*, 1993; Sawaya *et al.*, 1996; Lissner *et al.*, 1989; Martin *et al.*, 1996; Black *et al.*, 1995; Velthuis-te Wierik *et al.*, 1995; Warwick & Baines, 1996; Goris *et al.*, 2000; 2001a; 2001b, Goris & Westerterp, 1999). In the four studies by Goris and colleagues, weight was gained (Goris *et al.*, 2001a; 2001b, Goris & Westerterp; 1999) or maintained (Goris *et al.*, 2000) during a pre recording week while weight was lost during the following week when food intakes were recorded. In addition, these four studies determined how much undereating contributed to overall energy underreporting by calculating the energy cost of the weight lost as a proportion of underreported energy intake. The results showed that undereating accounted for 0 to 100% of underreporting. The weight loss in one study was not significantly different from zero and hence no undereating occurred (Goris *et al.*, 2001a). In another study, there was evidence of undereating during a second 7 day food record but not in the first 7 day record, 12 weeks previously (Goris *et al.*, 2001b). In obese men, 70% of underreported energy intake was due to undereating (Goris *et al.*, 2000) and, in normal weight dietitians, all of the underreported energy intake was due to undereating (Goris & Westerterp, 1999). The undereating in this group of dietitians mentioned above was described as unintentional (Goris & Westerterp, 1999) as they reported that they had not changed their eating habits during the study.

Underrecording

In the absence of information on changes in body weight, it is impossible to differentiate between underrecording and undereating. In Table 1.7, four of the studies showed weight gain while food intakes were recorded despite underreporting of energy

intakes. This suggests that not all foods eaten were recorded. Two of the studies in adolescents showed a mean weight gain in both obese and non-obese adolescents (Bandini *et al.*, 1990) and in 15 year old boys (Bratteby *et al.*, 1998) while 15 year old girls lost weight while keeping a 7 day food record (Bratteby *et al.*, 1998). Energy intake was underreported in both of these studies suggesting underrecording rather than undereating. Taren *et al.*, (1999) showed that underreporters gained weight and overreporters lost weight over nine days of which food intake was recorded for three days. If the 3 days were representative of the full nine days, this suggests that the underreporters didn't record all foods eaten and that the overreporters did overreport their food intake. There was a mean increase in body weight in only one study in adults (Asbeck *et al.*, 2002), which also suggested underrecording as 37% of the sample was identified as underreporters.

Goris and colleagues measured underrecording by comparing reported water intake and metabolic water (from the oxidation of nutrients) to water loss measured by doubly labelled water. Water intake below water loss measures underrecording. In the four studies by Goris and colleagues in Table 1.7, underrecording, using this method, accounted for 100% (Goris *et al.*, 2001a), 55% (Goris *et al.*, 2001b), 30% (Goris *et al.*, 2000) and 0% (Goris & Westerterp, 1999) of underreported energy intakes. This method is limited, however, by the assumption that water and food intakes are reported with equal accuracy.

Dieting

Intentional undereating is dieting. There are no clear data on the prevalence of dieting in different populations. In a postal survey of Irish adults, 12% were currently dieting (Friel *et al.*, 1999) while 12% of women and 4% of men in the DNSBA sample reported current dieting (Gregory *et al.*, 1990) and 9% of US women in the Continuing Food Survey of Individuals (CFSII) were dieting during the study (Ballard Barbash *et al.*, 1996). These are most likely conservative estimates of current dieting as 70% of US adults reported actively trying to lose weight in the last four years (French *et al.*, 1999) while, in a representative sample of UK adults, 36% reported 'watching their weight' and 28% were 'trying to lose weight' (Wardle *et al.*, 2000). In addition, a total of 35% of Dutch adults were currently trying to lose weight. Even normal weight and underweight female students in Spain wanted to lose weight (Ortega *et al.*, 1996).

There is a clear relationship between wishing to lose weight and underreporting as a history of dieting, desire to lose weight and restrained eating have all be shown to independently predict energy underreporting as has being overweight or obese (see Table 1.4 Characteristics of Underreporters). Individuals currently dieting to lose weight are expected in any large study of food intakes. It is probable that these individuals will record low energy intakes and lose weight and as such are frequently excluded from data analysis (Pryer *et al.*, 1997; Heerstrass *et al.*, 1998; Trichopolou *et al.*, 2001). In addition, it appears that others who wish to lose weight will diet (undereat) during the study period or report lower food intakes (underrecord).

Recording food intake is closely linked with losing weight so it is not surprising that keeping a food record is an opportunity for many subjects to diet. In studies where food intake records were kept on more than one occasion, energy underreporting increased with repeat food records (Johannson *et al.*, 1992; Milne *et al.*, 1991) and individual underreporters from the first record were significantly likely to underreport during subsequent records also (Price *et al.*, 1997; Black & Cole, 2001). Goris & Westerterp (2000) showed, however, that when dietitians were confronted about their undereating and subsequent weight loss during a 7 day food record, they provided an accurate second record.

Macdiarmid & Blundell (1997) asked 100 subjects who had completed a 7 day weighed intake if they changed their eating habits during the 7 days. A total of 46% said they had as they were either more conscious of what they ate, more embarrassed about specific foods eaten or found the method too inconvenient. In addition, some individuals with a low EI/BMR (< 1.2) claimed that they had reported their food intake accurately leading the authors to suggest that these subjects may have adjusted either their food intake or their food record knowingly or unknowingly. Two mechanisms to describe the association between increased energy underreporting in restrained eaters were suggested by Asbeck *et al.*, (2002). First, the increased self-observation when keeping a food record increases self-control in general and secondly, restrained eaters have a strong self-image of being capable of controlling and decreasing their energy intake. Furthermore, the higher disinhibition seen in men who underreported their food intake in Asbeck's study may lead to uncontrolled intake that is not recorded.

1. 6 Dietary Assessment Methodologies

Aspects of dietary assessment may results in an under or over estimation of energy intake and a subsequent misrepresentation of energy underreporting.

Memory/recall

All methods depend on the recall of foods eaten either during the previous day (24 hr recall), or as part of usual food intakes (FFQ and diet history) or as part of a prospective food record. Inability to recall foods eaten will lead to lower reported energy intakes.

Portion size

All methods also require an estimate of amount of each food eaten. Weighed food records are not dependent on estimated of portion sizes but are generally more inconvenient for subjects. Portion sizes are estimated in a whole series of ways e.g. comparisons to average portions, comparisons to photographs of portions and food models. In a review of the use of portion sized in dietary assessment, Young & Nestle (1995) reported than individuals vary in their ability to accurately estimate the amount of food eaten or the amount usually eaten. Under or overestimating portion sizes will alter reported energy and macronutrient intakes.

Literacy

Most dietary assessment methods require literacy and numerical ability to directly weigh and record foods eaten or in report the frequency of usual intake. Poor literacy may result in inaccurate records of both the types and quantities of foods eaten (Macdiarmid & Blundell, 1998).

Foods eaten 'out'

The proportion of food intake, and hence energy intake, eaten outside of the home is increasing (CSO, 1996; Irish Universities Nutrition Alliance, 2001). Accurately recording foods eaten in cafes and restaurants is challenging, as subjects may not recall the whole range of foods eaten and the amounts of foods eaten. In addition, the ingredients used in many dishes will be estimated which may lead to an over or underestimation of their energy content.

Nutrient databases

Foods eaten are converted to energy and nutrients using a variety of nutrient analysis software packages based on different food composition data. The food composition database used is unlikely to include all foods eaten in a large dietary survey. Furthermore, while food composition databases generally provide complete data on the energy content of foods they may not do so for nutrients (Cowin & Emmett, 1999).

Interviewer motivation

All dietary assessment methods rely on the motivation of both the subject and the interviewer/fieldworker. In EPIC, a total of 70 interviewers collected 24 hour recalls using a computer-assisted method called EPIC-SOFT. Slimani *et al.*, (2000) showed statistical differences in mean energy intakes between interviewers in 2 of 7 countries for men and 4 of 8 countries for women. The greater difference in EI between interviewers for women than for men was suggested to relate to the higher prevalence of energy underreporting in women.

While some of the above influences on food intake recording will be uniform across a survey sample (e.g. completeness of food composition database), some may impact of subgroups of the sample to a greater extent (e.g. those who eat out most, those with least literacy).

1.7 Basal Metabolic Rate

A measurement or estimate of basal metabolic rate (BMR) is required for all subjects when using the Goldberg cut-offs to identify underreporters. While BMR can be measured by direct or indirect calorimetry, most dietary surveys use predictive equations, based on age, sex and body weight, to estimate BMR. The Schofield equations, which are widely used to estimate BMR, (Schofield *et al.*, 1985) are outlined in Table 1.8.

Table 1.8 Schofield Equations for estimating BMR (MJ/day)

Males	10-17years	BMR = 0.074(weight) + 2.754
	18-29years	BMR = 0.063(weight) + 2.896
	30-59years	BMR = 0.048(weight) + 3.653
	60-74years	BMR = 0.0499(weight) + 2.930
	75years-	BMR = 0.0350(weight) + 3.434
Females	10-17years	BMR = 0.056(weight) + 2.898
	18-29years	BMR = 0.062(weight) + 2.036
	30-59years	BMR = 0.034(weight) + 3.538
	60-74years	BMR = 0.0386(weight) + 2.875
	75years-	BMR = 0.041(weight) + 2.610

The equations were based on a database of 114 published studies representing 7173 BMR measurements (Schofield *et al.*, 1985). Adults over 60 years were underrepresented in the database and revised equations for those over 60years were developed by the U.K. Department of Health (1991) based on additional BMR measurements on 450 adults. The revised equations for adults over 60 years are included in Table 1.8

It has been suggested that the equations overestimate BMR due to the inclusion of 3000 BMR measurements from Italian soldiers (Shetty *et al.*, 1996). Indeed 45% of the BMR data used for the predictive equations were from Italians (Schofield *et al.*, 1985). Hayter & Henry (1994) used the Schofield database and further BMR measurements to determine if there were differences in BMR between the geographic regions most represented in the data (Northern Europe, America, Italy, China, India). They found that the regression equations to predict BMR were highest in Italian men and women thereby suggesting that the Schofield equations may be biased to overestimation of BMR in other populations. The higher BMR in Italians was confirmed by De Lorenzo *et al.*, (2001) but the equations provided an accurate estimate of mean BMR in all weight categories in Italians. Differences in measured and estimated BMR were however, found at an individual level. While Piers *et al.*, (1997) showed that the equations overestimated BMR in Australian adults, other investigators have reported

that the equations accurately predict mean BMR in obese and non obese adolescents (Dietz *et al.*, 1991), lean men and women (Bucholz *et al.*, 2001) and in infants, adolescent and adults (Butte *et al.*, 1995). At an individual level, it is acknowledged that BMR predicted by the equations will vary from measured BMR by 8% to 12% (Piers *et al.*, 1997).

Recently, Horgan & Stubbs (2003) reported that the Schofield equations overestimated BMR in the obese, while O'Reilly *et al.*, (Personal communication, 2000) reported that this overestimation of BMR artificially increased the degree of energy underreporting in a large dietary survey using the Goldberg cut-offs. The validity of estimated BMR using the Schofield equations in subgroups within populations clearly needs further investigation to ensure that energy underreporting is identified with accuracy by the Goldberg cut-offs.

1.8 Physical Activity Levels

Black *et al.*, (2000a) recommended the collection of physical activity data in dietary surveys to provide suitable physical activity levels (PALs) for the calculation of the Goldberg cut-offs for EI/BMR in the survey sample. While physical activity data are collected in epidemiological surveys, including dietary surveys, to examine the relationship between physical activity and health, this review focuses on physical activity levels for inclusion in the Goldberg equation only.

1.8.1 Physical Activity Levels and Energy Requirements

Physical activity levels have been used for almost 20 years to describe energy requirements. The FAO/WHO/UNU (1985) expert consultation on energy and protein requirements was first to express energy requirements in adults as multiples of basal metabolic rate (BMR). This ratio of energy expenditure: BMR was called a 'physical activity level'. The FAO/WHO/UNU (1985) report proposed the following PALs to describe energy requirements (Table 1.9).

Table 1.9 Energy requirements in adult men and women described as physical activity levels (FAO/WHO/UNU, 1985)

	Occupational Activity		
Men	Light	Moderate	Heavy
Men	PAL = 1.55	PAL = 1.78	PAL = 2.10
Women	PAL = 1.56	PAL = 1.64	PAL = 1.82

The factorial approach was used to calculate the above PALs where the energy cost of activities, expressed as multiples of BMR, were totalled. The following activities were identified: sleep, occupational activities, discretionary activities (described as 'socially desirable, household and cardiovascular and muscular maintenance' activities). Energy expenditure while asleep was taken as 1.0 x BMR. Occupational activities were classified as light, moderate or heavy work. The report describes how the energy costs of these categories of work activities were derived which is presented here in Table 1.10 (an edited table from the report). The time spent sitting, standing and at specific work tasks and the energy costs of these activities were composite values from published and unpublished data assembled by the expert consultation group.

Table 1.10 Energy cost of three grades of physical activity at work for men (based on 18-30year old, 65kg, BMR 1.79 kcal/min) and women (based on 18-30year old, 55kg, BMR 1.51kcal/min)

	Men		Women	
	Kcal/min	PAL	Kcal/min	PAL
Light Work.				
75% of time sitting/standing.	1.79		1.51	
25% of time standing/moving.	2.51		1.70	
Average	1.99	1.7	1.56	1.7
Moderate Work.				
25% of time sitting/standing.	1.79		1.51	
75% at specified occupational activity.	3.61		2.20	
Average	3.16	2.7	2.03	2.2
Heavy Work.				
40% of time sitting/standing.	1.79		1.51	
60% of time at specific occupational activity.	6.22		3.21	
Average	4.45	3.8	2.54	2.8

Discretionary activities were given an energy cost of 2.5 - 3.0 x BMR. All other time not accounted for was given an energy cost of 1.4 x BMR to account for washing, dressing and standing.

The U.K. Department of Health report 'Dietary Reference Values for Food, Energy and Nutrients for the United Kingdom' (1991) also presented energy requirements as multiples of BMR. The term 'physical activity ratio' (PAR) was used to describe the energy cost of activities as multiples of BMR. A matrix of PAL was presented which included men and women at three levels of both occupational and non-occupational activity (Table 1.11). The calculations were based on the assumption that 'bed' accounts for 8 out of 24 hours and that work accounts for 5.5 hours per day (an average working day of 7.5hours over 5 days). The remaining 10.5 hours of non-occupational activity was divided into one of three categories based on 2 hours of activity at different PAR levels and 8.5 hours at an arbitrary PAR of 1.4. The three categories were for 'non active', 'moderately active' and 'very active' people' where the 2 hours were spent at energy expenditures of BMR x 2, BMR x 3 and BMR x 4 respectively. This gave an overall non-occupational energy cost for the 10.5 hours of BMR x 1.5 for the 'non active', BMR x 1.7 for the 'moderately active' and BMR x 1.9 for the 'very active'.

Table 1.11 Calculated Physical Activity Levels (PALs) of adults at 3 levels each of occupational and non-occupational activity (Department of Health, UK, 1991).

Non-occupational Activity	Occupational Activity					
	Light		Moderate		Moderate/Heavy	
	M	F	M	F	M	F
Non-active	1.4	1.4	1.6	1.5	1.7	1.5
Moderately active	1.5	1.5	1.7	1.6	1.8	1.6
Very Active	1.6	1.6	1.8	1.7	1.9	1.7

The report stated that "in the absence of further information, UK population groups should be assumed to have light occupations and non-active occupational activity, and a PAL of 1.4". The report also outlined that more detailed information on time spent at specific activities could estimate energy expenditure in groups more accurately but stated that, in order to estimate daily energy expenditure of individuals, it is necessary to have a measurement of BMR, detailed time use data and activity description and, if possible, measurements of the energy costs of activities.

The 1993 report 'Nutrient and Energy Intakes for the European Community' (Scientific Committee for Food, 1993) also described energy requirements as physical activity levels. Energy requirements were presented in men and women according to (i) age group, (ii) BMR based on desirable or actual body weight and (iii) with or without additional desirable recreational activity as outlined in Table 1.12 Actual body weights were as observed in many European studies while desirable body weights were based on BMI of 22. Desirable activity refers to activity for health benefits.

Table 1.12 Energy Requirements for European Men and Women expressed as Physical Activity Levels (Scientific Committee for Food, 1993)

	Desirable body weight		Actual body weight	
	With desirable activity	Without desirable activity	With desirable activity	Without desirable activity
Men				
18-29yrs	PAL = 1.77	PAL = 1.67	PAL = 1.77	PAL = 1.67
30-59yrs	PAL = 1.66	PAL = 1.55	PAL = 1.67	PAL = 1.56
60-74yrs	PAL = 1.51	PAL = 1.40	PAL = 1.51	PAL = 1.40
≥ 75yrs	PAL = 1.51	PAL = 1.33	PAL = 1.51	PAL = 1.33
Average	PAL = 1.67	PAL = 1.56	PAL = 1.68	PAL = 1.57
Women				
18-29yrs	PAL = 1.63	PAL = 1.52	PAL = 1.63	PAL = 1.52
30-59yrs	PAL = 1.60	PAL = 1.49	PAL = 1.60	PAL = 1.49
60-74yrs	PAL = 1.56	PAL = 1.44	PAL = 1.56	PAL = 1.44
≥ 75yrs	PAL = 1.56	PAL = 1.37	PAL = 1.56	PAL = 1.37
Average	PAL = 1.60	PAL =1.48	PAL = 1.60	PAL = 1.48

These energy recommendations were adopted for Ireland in 1999 (Food Safety Authority of Ireland, 1999).

1.8.2 Energy Costs of Activities for use when calculating PAL

The energy costs of 167 work and recreational activities, expressed as PALs, were collated by James & Schofield (1990). The total number of subjects from which the PAL for each activity was derived was also presented, ranging from less than 5 subjects for many activities to more than 100 subjects of other activities. Subsequently in 1993, Ainsworth *et al.*, published the energy costs of over 500 occupational and recreational

activities as multiples of resting metabolic rate called METS from reviewing published and unpublished energy expenditure data. One MET is resting energy expenditure described as the energy cost of sitting quietly which for an average adult is approximately 3.5mls oxygen/kg body weight per minute or 1kcal/kg body weight/hour (Ainsworth *et al.*, 1993). These MET scores have been widely used in calculating PALs and energy expenditure from physical activity questionnaires.

1.8.3 Physical Activity Levels from Doubly Labelled Water Measurements of Energy Expenditure

Doubly labelled water measurements provide a more accurate measurement of energy expenditure over a particular time frame that the factorial methods described above. Black *et al.*, (1996) published mean PALs from all doubly labelled water studies at the time which were presented earlier in Table 1.1 with the observation that the PALs reported were higher than the FAO/UNU/WHO (1985) value of 1.55 for sedentary activity that was used by Goldberg *et al.*, (1991). Black *et al.*, (1996) also identified the extremes of energy expenditure. At the lower end of the scale, a mean PAL of 1.21 was found in four studies in which EE was either measured in chair-bound subjects or in those confined to a calorimeter. At the upper end of the scale, a distinction is made between the maximum (physical activity) achievable over a period of time and the maximum sustainable as a long-term way of life. PALs of greater than 4.0 were achieved in Tour de France cyclists over the 21 days of the competition (Westerterp *et al.*, 1986) and in sled hauliers over 20 days of activity in the Artic (Stroud *et al.*, 1993). Other studies with PALs of 2 to 3.5 were based on data from athletes in training, which is unlikely to represent sustainable activity over a long period of time. The studies with PALs of 2.0 to 2.3 were based on subjects in routine training, which could be maintained over long periods of time. In conclusion, Black *et al.*, (1996) suggested that PALs in the range of 1.2 to 2.5 represented sustainable lifestyles.

1.8.4 Methods to Measure Physical Activity in Dietary Surveys

While physical activity level in this literature review thus far has described the ratio of EE/BMR, the US Surgeon General's definition of physical activity is 'any bodily movement that is produced by the contraction of skeletal muscle that substantially increases energy expenditure' (US Department of Health and Human Services, 1996). In the free living situation, doubly labelled water measures of total energy expenditure (including physical activity), are frequently impractical as the method is both expensive

and requires technical ability (Livingstone & Black, 2003). There is however, a variety of alternative methods to measure physical activity in dietary surveys.

Physical Activity Questionnaires

There are many different questionnaire-based methods used to describe physical activity in epidemiological studies. In an extensive review of 31 physical activity questionnaires, Kriska & Casperen (1997) showed that the questionnaires differed in the way they were administered, the target population in which they can be used, the time frame over which activity was assessed and the type of activity which was measured. The main advantage of physical activity questionnaires over other methods, according to Kriska & Casperen (1997), is that behaviour isn't altered. In addition, questionnaires are practical in the free-living studies as they are inexpensive to administer and are relatively convenient for the participant to complete (Kriska & Casperen, 1997). On the other hand, Wareham & Rennie (1998) highlighted the disadvantages of questionnaires in measuring physical activity. In the first place, most questionnaires focus on only some aspects of activity in daily living (e.g. leisure or work activities) rather than all activities. The scope of the 31 questionnaires presented by Kriska & Casperen (1997) was collated by the present author showing that most focused on leisure and occupational activities (Table 1.13)

Table 1.13 Activity assessed by 31 Physical Activity Questionnaires presented by Kriska & Casperen (1997)

Activity Components	Number of Questionnaires
Leisure only	10 questionnaires
Leisure & occupational activities	10 questionnaires
Leisure, occupational and home activities	3 questionnaires
Leisure and household activities	3 questionnaires
Occupational activities only	1 questionnaire
Household, exercise and recreational activities	1 questionnaire
Leisure, occupational, transportation and home work	1 questionnaire
Leisure and school activities	2 questionnaires

Wareham & Rennie (1998) also commented that questionnaires are most effective at measuring easily recalled activities which are generally sporting/recreational activities

that the individual chooses to do for a set time e.g. swimming, jogging, aerobics. On the other hand, questionnaires provide less accurate estimates of light or moderate activities, which are difficult to recall precisely (Wareham & Rennie, 1998). Questionnaire-based physical activity information is self-reported and may be prone to overestimation. Norman *et al.*, (2001) showed that activity was overestimated by a questionnaire compared to an activity record, particularly in older adults and in those with a BMI greater than 26. Lichtman *et al.*, (1992) showed that obese adults, who claimed to have difficulty losing weight despite energy restriction, underestimated their energy intake and overestimated their physical activity in a 14 day activity record compared to DLW measurements of EE over the same 14 days. The results of physical activity questionnaires are generally presented as METS rather than as actual energy expenditure.

Activity Records

Activity records/diaries require subjects to prospectively record all activities over a given time-period, (e.g. 3 days to 14 days) in regular intervals (e.g. every 15 minutes, every 30 minutes). They are appealing for large population surveys as they are relatively uncomplicated and inexpensive. They do, however, require consistent co-operation by subjects and are open to the same self-reported bias as questionnaires (Wareham & Rennie, 1998). Using the energy costs of activities recorded, the results can be presented as energy expenditure, PALs or METS.

Movement Sensors

Movement sensors (accelerometers) estimate movement. The simplest device is a uniaxial accelerometer (e.g. pedometer), which counts steps taken (Wareham & Rennie, 1998). The results are presented as counts per minute or as energy expenditure using regression equations. More complex accelerometers, e.g. triaxial accelerometers, measure acceleration in the anterior, mediolateral and vertical direction of the trunk. Goris *et al.*, (2000) reported the use of this method in calculating EE based on a regression equation from doubly labelled water measurements of EE.

Heart Rate Monitoring

Heart rate monitoring has been shown to be a reliable measure of EE when it is used in combination with measures of resting metabolic rate and an assessment of the individual relationship between EE and heart rate (Rennie *et al.*, 2000).

While many food intake studies have also included measurements of physical activity, relatively few have used the physical activity data in identifying underreporters. A total of 20 studies that compared energy intakes and energy expenditure were discussed earlier and presented in Table 1.2. Of the three studies that used accelerometers to measure physical activity, two were by the same author (Goris & Westerterp, 1999; Goris *et al.*, 2001) and energy expenditure was calculated using previously derived equations. Horner *et al.*, (2002) also used predictive equations to calculate energy expenditure from uniaxial accelerometer measurements. The five studies that collected physical activity data using activity diaries calculated energy expenditure using the factorial method, where the energy costs of activities were expressed as multiples of BMR and then totalled (Milne *et al.*, 1991; Rothenberg *et al.*, 1998; Körtzinger *et al.*, 1997; Gilliat-Wimberley *et al.*, 2001; Arroll *et al.*, 1991). A total of five other studies measured physical activity at work and leisure using a questionnaire. In three of these studies, respondents were categorised as low, medium or high activity and the FAO/WHO/UNU (1985) PALs were used to calculate energy expenditure (Heitmann & Lissner, 1995; Meirelles *et al.*, 2001; Heitmann et al., 2002). In one study, the formula EE = BMR*1.5 - x + y (from FAO/WHO/UNU (1985)) was used where x and y represent the energy cost of different activities in work and leisure measured by the questionnaire (Lindross *et al.*, 1993). In another study, respondents placed themselves in a matrix of 4 categories of leisure activity and 5 categories of work activity with corresponding PALs (Høidrup *et al.*, 2002). Each of the above studies identified underreporters by directly comparing EI and EE, unlike the Goldberg cut-off, which included the variations in measurements of both EI and EE. Haraldsdöttir & Sandstrom (1994) recalculated the Goldberg cut-off using a study-specific PAL from earlier weight maintenance studies, and showed that the prevalence of underreporting was 6% compared to less than 1% when a PAL value of 1.55 was used in the Goldberg equation.

In summary, there has been extensive research over the past 15 years on energy underreporting. This research has focused on identifying energy underreporters, characterising underreporters, exploring the mechanisms involved in energy underreporting and examining the influence of energy underreporting on the interpretation of food and nutrient intakes.

1.9 Aim and objectives of this thesis

The aim of this thesis is to address energy underreporting in the North/South Ireland Food Consumption Survey (NSIFCS). This survey collected food and nutrient intakes, anthropometric measurements, health and lifestyle information and physical activity data on 1379 adults, a representative sample of the populations of both Northern Ireland and the Republic of Ireland between 1997 and 1999.

The specific objectives are as follows.

1. To describe energy intakes in Irish adults and to determine the prevalence of energy underreporting using the Goldberg cut-offs as published in 1991.
2. To generate an estimated physical activity level for each respondent using data from a self-administered physical activity questionnaire which described activity at home, work and in recreation over the previous year.
3. To use the respondent-specific estimated physical activity levels to recalculate the Goldberg cut-offs and subsequently determine the prevalence of underreporting in Irish adults based on current physical activity levels.
4. To examine the impact of identifying underreporters, using study and respondent-specific physical activity levels, on both the characteristics of underreporters and on their nutrient intakes.
5. To examine the relationship between changes in body weight over the study period with energy underreporting.

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Chapter 2

Personal Contribution of the Author to the North/South Ireland Food Consumption Survey

2.1 Background

The North South Ireland Food Consumption survey was carried out by the Irish Universities Nutrition Alliance (IUNA), which is a formal alliance of the academic nutrition centres at University College Cork, Trinity College Dublin and University of Ulster. The survey teams were based at the nutrition units of the three universities with a co-ordinating nutrition scientist in each unit. I was employed as a research assistant/nutritionist between March 1997 and October 2001 in Trinity College Dublin.

The following describes the different aspects of the survey in which I was involved.

2.2 Survey Methodology

Between March 1997 and June 1997, I worked within the survey team in agreeing and designing various aspects of the survey methodology.

2.3 Feasibility & Pilot Studies

These was carried out during June and October 1997 during which I collected, coded, quantified and entered data from two 'clusters'.

2.4 Main data collection, data entry (Oct 1997 – Oct 1999)

I located, recruited and collected data for 200 subjects (15%) out of a total of 1379 respondents from Northern Ireland and the Republic of Ireland, who participated in the survey. I was responsible for quantifying, coding and checking the food intake data and for the subsequent data entry for these 200 respondents, according to the survey methodology as was subsequently described by Harrington *et al.*, (2001). I was also responsible for checking, coding and data entry for the questionnaire data on these 200 respondents.

2.5 Data analysis

Each fieldworker was involved in the quality control of the SPSS relational databases generated and the subsequent analyses of the database to generate the summary report (IUNA, 2001), the main report from the survey (www.iuna.net) and a series of scientific papers, published as a supplement in Public Health Nutrition (Vol. 4 (5A) 2001).

Each of the research chapters in this thesis was of my own design, under the supervision of Professor Michael Gibney (Trinity College Dublin) and using the databases from the North/South Ireland Food Consumption Survey.

2.6 References

Harrington, K.E., Robson, P.J., Kiely, M., Livingstone, M.B.E., Lambe, J., & Gibney, M.J. (2001). The North/South Ireland Food Consumption Survey: Survey Design and Methodology paper. *Public Health Nutrition, 4,* 1037-1042.

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Chapter 3

An evaluation of energy intakes and the ratio of energy intake to estimated basal metabolic rate (EI/BMR_{est}) in the North/South Ireland Food Consumption Survey

McGowan MJ, Harrington KE, Kiely M, Robson PJ, Livingstone MBE, Gibney MJ.
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3.1 Abstract

Objective: To examine energy intakes (EI), their ratio to estimated basal metabolic rate (BMR_{est}) and the contribution of food groups to energy intake in the North/South Ireland Food Consumption Survey.

Design and setting: Random sample of adults from the populations of Northern Ireland and the Republic of Ireland. Food intake data were collected using a 7 day food diary. Body weight and height were measured and EI/BMR_{est} was calculated from reported energy intake and estimated basal metabolic rate. Dieting practices were assessed as part of a self-administered questionnaire.

Results: Mean daily energy intake in men was 11.0MJ and in women was 7.6MJ, which was comparable to reported energy intakes in Northern Ireland and the Republic of Ireland over a decade ago. Mean EI/BMR_{est} was 1.38. This increased to 1.42, after the exclusion of dieters and those who were unwell, but still remained less than the established cut-off of 1.53. EI/BMR_{est} was significantly ($P<0.05$) higher in men than women and decreased significantly ($P<0.05$) with increasing BMI in both sexes. The four food groups that contributed 50% of energy in men and women were meat and meat products, breads and rolls, potatoes and potato products and biscuits, cakes, pastries and puddings.

Conclusions: Energy intakes in adults have not changed remarkably in Northern Ireland or the Republic of Ireland in the last 10 years but the mean EI/BMR_{est} of 1.38 suggests that energy underreporting occurred. EI/BMR_{est} was lower in women and in the overweight/obese. Additional multivariate analysis of the data is needed to identify more clearly the subgroups of the population reporting lower than expected energy intakes and to evaluate the effect of low energy reporting on the consumption of various foods and food groups.

3.2 Introduction

Energy intakes are the fundamental results of food intake surveys. Actual nutrient and recommended nutrient intakes are frequently expressed in terms of energy intake with macronutrients described as a percentage of total energy or food energy intake and micronutrients described as actual intake per MJ or per 1000kcals. Furthermore, it is through an evaluation of the validity of energy intakes that the validity of reported food intakes have been examined (Black *et al.*, 1991; DeVries *et al.*, 1994; Briefel *et al.*, 1995). Accurate food intake data are required to interpret trends in food, energy and nutrient intakes and to interpret the association between diet and disease. The validity of reported food intake data has been frequently queried. No standard method of food intake data collection exists to which reported food intake data can be compared (Bingham, 1994; Livingstone, 1995), whereas reported energy intake, expressed as a ratio of energy intake to estimated basal metabolic rate (EI/BMR_{est}), can be compared to expected energy expenditure to assess the validity of energy intakes (Black *et al.*, 1991; Goldberg *et al.*, 1991; Bingham, 1994; Livingstone, 1995).

With increasing prosperity and a wider selection of food choices than ever before, it is likely that food intakes in both the Republic of Ireland and Northern Ireland are changing. It is, however, over a decade since food consumption data were collected in the Republic of Ireland (Lee & Cunningham, 1990) and in Northern Ireland (Barker *et al.*, 1989). The North/South Ireland Food Consumption Survey (NSIFCS) provides current information on food and nutrient intakes in both the Republic of Ireland and Northern Ireland. The aim of this paper is to report energy intakes from the NSIFCS, to examine mean EI/BMR_{est} in men and women according to age and body mass index and to investigate the contribution of food groups to energy intakes.

3.3 Methods

Survey sample

A detailed description of the survey design and sampling procedures are given by Kiely *et al.* (2001). In brief, individuals were selected at random from the electoral register and invited by letter to take part. Fieldworkers contacted all individuals selected. Pregnant women, lactating mothers and persons aged 65y or above were not considered eligible for the survey. In total, 1379 people aged 18-64y took part. This constituted 63% of the eligible sample. This study collected food intake data, anthropometric

measurements and extensive questionnaire information on lifestyles, health, attitudes, physical activity and restrained eating.

Food Intake

Food intake data were collected using a food diary over a 7 day period. The protocol for the completion of the food diary has been described in detail elsewhere in this supplement (Harrington *et al.*, 2001) and involved up to 4 visits by a fieldworker, to each respondent, over the period of the food diary record. Respondents recorded the date, day, time, location and definition of eating occasion for each meal/snack/beverage taken. For each item of food or drink, the respondent recorded the name of the item, including brand name if applicable, the amount of the item eaten/drunk and the cooking method used, if applicable. For composite dishes, the respondent recorded the ingredients of the dish and the number of servings, which it provided. A combination of methods was used to quantify foods and drinks recorded. A food photographic atlas was specifically designed for the survey. Respondents compared portions of foods eaten to photographs of known weights of these foods. Replicates of some foods were weighed directly by the fieldworker during visits to the respondent's home. Manufacturer's data were used to quantify manufactured products. Household measures were also used by both fieldworkers and respondents to describe the quantity of a food or drink. Standard portion sizes were only used when necessary (MAFF, 1994; Harrington *et al.*, 2001). Respondents were encouraged not to alter their food or drink choices during the course of the food diary recording week.

Coding and nutrient analysis

Data collected were coded for each subject, according to Mc Cance and Widdowson's The Composition of Foods (Holland *et al.*, 1995) and published supplements (Holland *et al.*, 1988; Holland *et al.*, 1989; Holland *et al.*, 1991; Holland *et al.*, 1992; Holland *et al.*, 1993; Chan *et al.*, 1994; Chan *et al.*, 1995; Chan *et al.*, 1996; Holland *et al.*, 1996), and analysed for nutrients using WISP© (Weighed Intake Software Program) (Tinuviel Software, Warrington, U.K.). The nutrient database was expanded by the addition of the nutritional information of 860 extra foods/dishes eaten by respondents. These foods/dishes were either not present in the original database or were nutritionally different from similar foods in the database. The nutritional information was obtained from either recipes or manufacturer's information. Foods were also aggregated into 18

food groups to ascertain the contribution that each food group made to mean daily energy intakes.

Weight, height and body mass index (BMI)

Body weight was measured, by the fieldworker using a Seca 770 digital personal weighing scales (CMS Weighing Equipment Ltd., London, U.K.) to the nearest 0.1kg (n=1379). Respondents were weighed while wearing light clothing, without shoes and after voiding. Height was measured (n=1312) using the Leicester portable height measure (CMS Weighing Equipment Ltd., London, U.K.) to the nearest 0.01cm. BMI (kg/m^2) (Garrow, 1974) was used to classify respondents as normal weight, overweight or obese (World Health Organisation, 1995).

Estimated Basal Metabolic Rate (BMR_{est})

Estimated Basal Metabolic Rate (BMR_{est}) was calculated using body weight by standard equations devised by Schofield (Schofield *et al.*, 1985), for those aged 18-59 years, and by the equations used in the 1991 UK Dietary Reference Values (Department of Health, 1991), for those aged 60 years or more. Energy intake was expressed as a ratio of estimated BMR (EI/BMR_{est}) for each respondent and examined according to sex, age and BMI.

Dieting practices

As energy intakes may be influenced by dieting practices, questionnaire data collected information on dieting. Respondents were asked if they were "meant to be following a particular diet at the moment". Those who answered that they were meant to be following a "low fat", "weight reducing" or "cholesterol lowering diet" and who said that they followed the diet either "always" or "most of the time" were considered to be dieters. As energy intakes may also be influenced by illness/poor health, respondents were asked if their eating habits, during the week of the survey, had been affected by being unwell. EI/BMR_{est} was examined according to sex, age and BMI, excluding those considered to be dieters and those who reported that their food intake was reduced due to being unwell during the week of the survey.

Statistical analysis

Mean $\pm$ SD energy intakes were calculated for men and women in each age group. Mean $\pm$ SD EI/BMR_{est} values were calculated for men and women in each of the age

groups and BMI categories, for the full sample and after excluding dieters/unwell. As energy intakes and mean EI/BMR_{est} values were normally distributed in men and women in each of the age groups, an independent t test was used to test for differences in energy intake and EI/BMR_{est} between men and women. A one-way analysis of variance (ANOVA) was used to test for differences in energy intakes and EI/BMR_{est} between age groups and/or BMI categories followed by the Scheffe post hoc test when groups had equal variances or the Tamhane post hoc test when groups had unequal variances (Coakes & Steed, 1999).

The contribution of food groups to energy intake was calculated for the total population and for men and women in each of the age categories. As the sample size was large, small differences in the percentage of energy from food groups (> 1%) between men and women and between age groups showed statistical significance ($P<0.05$). Consequently, this paper focuses on a more descriptive approach to these results and highlights considerable differences in the percentage contribution of foods to energy. All statistical analysis was carried out using SPSS version 8.0 (SPSS Inc Chicago, USA).

3.4 Results

Mean daily energy intakes are presented in Table 1 for men and women in three age groups (18-35y, 36-50y and 51-64y). Men had a significantly ($P<0.001$) higher energy intake than women (11MJ Vs 7.6MJ). This was consistent across all 3 age groups. Energy intakes decreased significantly ($P<0.05$) with age in men and women with men and women aged 51-64y reporting significantly ($P<0.05$) lower energy intakes than younger men and women (Table 1).

Mean values for EI/BMR_{est} are given in Table 2. Overall, men had significantly higher values than women ($P<0.05$) and this was consistent across all age groups. For all subjects combined, mean EI/BMR_{est} declined significantly ($P<0.05$) with increasing BMI. When this was considered for age and sex groups, it tended to hold true between the normal and overweight BMI categories. However, EI/BMR_{est} tended not to decline between the overweight and obese category of BMI. These analyses are repeated in Table 3 where dieters and the unwell were excluded. Although the absolute values differ from Table 2, the main findings remain the same. Table 4 describes the contribution of 18 food groups to energy intake ranked according to level of

contribution. The percentage of the population who consumed foods from each food category is also given. The top four food groups that accounted for 50% of energy intake, were meat and meat products, breads and rolls, potatoes and potato products and biscuits, cakes, pastries and puddings. By and large, this was consistent across all age and sex groups. The percentage of men and women who were classified as consumers of the different food groups, tended to be broadly similar and generally constant across age groups. There were some differences between men and women and across the age groups but these tended to be small within the overall picture. For example, a higher percentage of women were consumers of biscuits, cakes, pastries and puddings than men (94% Vs 88%), a lower percentage of women were consumers of alcoholic beverages (61% Vs 70%) and of eggs and egg dishes (68% Vs 77%) than men. Similarly, across age groups there were some differences. For example, the proportion of the population who consumed biscuits, cakes, pastries and puddings increased with age in both men and women as did the percentage of respondents who consumed eggs and egg dishes and creams, ice creams and chilled desserts. The proportion of women who drank alcohol also decreased with age (Table 4).

3.5 Discussion

This study is the first food intake survey that has collected data in the Republic of Ireland and Northern Ireland simultaneously, using the same methodology. Although there were some differences in energy intakes between the present study and the 1990 Irish National Nutrition Survey (Lee & Cunningham, 1990) and the 1988 Diet, Lifestyle and Health in Northern Ireland Survey (Barker *et al.*, 1989) (differences of 0.3 to 1.2MJ per day), energy intakes did not change remarkably over the last decade in either the Republic of Ireland or Northern Ireland. It is necessary, however, to bear in mind that the method of food intake assessment used in each of the three surveys was different.

Energy intakes in this survey (11.0MJ for men and 7.6MJ for women) are comparable to the 1991 UK Dietary Reference Values (DRV's) (Department of Health, UK, 1991) which are expressed as estimated average requirements (EARs) and assume a physical activity level, expressed as a multiple of BMR, of 1.4. The recent Recommended Dietary Allowances for Ireland 1999 (Food Safety Authority of Ireland, 1999) followed the 1993 Nutrient and energy intakes for the European Community recommendations (Scientific Committee for Food, 1993) in expressing energy requirements in terms of actual body weight and ideal body weight (based on a BMI of 22kg/m^2) with and

without desirable physical activity levels of 1.51 to 1.77. The energy intakes in the present survey are lower than these recommendations. The body weights collected in this survey are, however, much higher than those used in the recommendations and the physical activity levels used in the recommendations are much higher than the mean physical activity level of 1.38 calculated from energy intakes in the present survey (Table 2). This suggests that these energy recommendations may need to be evaluated in the context of current energy intakes, actual physical activity levels and body weights in the Republic of Ireland and Northern Ireland.

This paper examines the validity of energy intakes. EI/BMR_{est} has been used extensively as a measure of the validity of energy intakes in food intake studies (Gregory *et al.*, 1990; Schoeller, 1990; Black *et al.*, 1991; Klesges *et al.*, 1995; Briefel *et al.*, 1997; Stallone *et al.*, 1997; Gnardellis *et al.*, 1998). Individuals with an EI/BMR_{est} below a certain cut-off limit have been categorised as underreporters (Briefel *et al.*, 1997; Hirvonen *et al.*, 1997; Lafay *et al.*, 1997; Stallone *et al.*, 1997; Gnardellis *et al.*, 1998; Becker *et al.*, 1999), low energy reporters (Price *et al.*, 1997; Pryer *et al.*, 1997), misreporters (Macdiarmid & Blundell, 1997), implausible reporters (Klesges *et al.*, 1995) or as individuals with "underestimated energy intake" (Haraldottir & Sandstrom, 1994). Goldberg *et al.* (1991), using data from whole-body calorimetry and doubly labelled water studies to determine energy expenditure, proposed a series of cut-off limits for EI/BMR_{est} to evaluate energy intake data. These cut-offs represent the 95% confidence interval of agreement between EI/BMR_{est} and a physical activity level of 1.55, taking into account daily variations in energy intake, physical activity levels and the precision of estimating BMR for sample sizes between 1 and 2000 with 1 to 28 days of food intake data. Energy intakes below these cut-offs have been described as being incompatible with long term survival (Goldberg *et al.*, 1991).

For a sample size of 1500 with 7 days of food intake data, Goldberg *et al.* (1991) proposed a minimum mean EI/BMR_{est} of 1.53. The mean EI/BMR_{est}, in the present study, was lower than this at 1.38 (1.45 in males, 1.31 in females) (Table 2) and continued to be lower than 1.53 when dieters and the unwell were excluded (1.42) (Table 3). However, the mean EI/BMR_{est} in this study was comparable to other surveys. The mean EI/BMR_{est} of 37 published studies of food intake was 1.43 (Black *et al.*, 1991). Similarly, low mean EI/BMR_{est} values have been seen in national food surveys in Sweden (EI/BMR_{est} 1.35 in males, 1.33 in females) (Becker, 1999) and in

Germany (mean EI/BMR_{est} 1.5 in males, 1.4 in females) (Hermann-Kunz & Thamm, 2000), which collected food intakes by means of a 7 day food diary.

In classifying individuals as underreporters/low energy reporters/misreporters the cut-off limit proposed by Goldberg *et al.* (1991) for a sample size of 1 has been used by many investigators (Haraldsdottir & Sandstrom, 1994; Klesges *et al.*, 1995; Price *et al.*, 1997; Pryer *et al.*, 1997; Gnardellis *et al.*, 1998; Johansson *et al.*, 1998). The cut-off relevant to the NSIFCS was 1.10 and 25% of respondents had an EI/BMR_{est} below this value (20% of men, 29% of women). Again, this is comparable to the results of other surveys. In a Swedish food survey 26% of respondents had an EI/BMR_{est} below 1.10 (Becker, 1999) and in the MRC National Survey of Health and Development in the UK, 21% of the non dieting sample had an EI/BMR_{est} below 1.10 (Price *et al.*, 1997). In the Dietary and Nutritional Survey of British Adults 49% of women and 29% of men had an EI/BMR_{est} below 1.2 (Gregory *et al.*, 1990). Recent work has shown that the aforementioned cut-offs do not identify all underreporters (Black, 2000) as the assumed physical activity level (PAL) of 1.55 is lower than that reported in many age and sex groups (Black *et al.*, 1996). It was suggested that different cut-offs relating to different activity levels are necessary to correctly identify individuals as low energy reporters (Black, 2000).

This issue of energy underreporting was taken into consideration in the development of the food diary protocol for this study. The keeping of a food diary requires a high level of participation by the respondent (Livingstone, 1995). The fact that a fieldworker visited each respondent up to 4 times and, in some cases more frequently, allowed the fieldworker to motivate and encourage the respondent in the completion of the food diary. It also helped reduce errors in food intake data collection related to both the omission of items eaten/drunk and the difficulties encountered by respondents in quantifying foods. Despite this intensive fieldworker involvement, mean EI/BMR_{est} values and the proportion of the population identified as underreporters (EI/BMR_{est} below 1.10) in this survey were not remarkably different than that reported in other large surveys of food intake.

In the evaluation of EI/BMR_{est} results many investigators exclude dieters and/or those who said their eating habits were affected by their health during the survey (Price *et al.*, 1997; Pryer *et al.*, 1997) as these respondents are expected to have lower energy intakes

than others. In this survey, 161 respondents (12%) were considered to be dieters and a further 10 respondents reported reduced food intake due to being unwell. After excluding these 171 (12.4%) respondents, mean EI/BMR_{est} did increase from 1.38 to 1.42 and the proportion of the sample with an EI/BMR_{est} below 1.10 decreased from 25% to 21%. Nonetheless, excluding dieters and the unwell certainly did not account for all of the low energy reporters. The question used to identify dieters may not have been exclusive in capturing all dieters as, in another question, 324 additional respondents (23% of the sample) reported that they had either reduced their calorie or fat intake or had made other dietary changes to lose weight during the previous year. These individuals were not categorised as dieters in the present study.

EI/BMR_{est} is not consistent within populations. In many food intake surveys, those who were overweight or obese were more likely to report lower than expected energy intakes than those whose weight was normal (Prentice *et al.*, 1986; Schoeller, 1990; Black *et al.*, 1991; Lichtman *et al.*, 1992; Heitmann & Lissner, 1995; Klesges *et al.*, 1995; Briefel *et al.*, 1997; Lafay *et al.*, 1997; Pryer *et al.*, 1997; Gnardellis *et al.*, 1998; Johansson *et al.*, 1998; Heitmann *et al.*, 2000). Indeed, BMI has been shown to be an independent predictor of low EI/BMR_{est} in large dietary surveys, in different countries (Hirvonen *et al.*, 1997; Price *et al.*, 1997; Pryer *et al.*, 1997). Other investigators showed that women (Lissner *et al.*, 1989; Livingstone *et al.*, 1990; Klesges *et al.*, 1995; Johansson *et al.*, 1998) and the weight conscious (Johansson *et al.*, 1998; Taren *et al.*, 1999) also reported low energy intakes. In this study, women had a significantly lower ($P<0.001$) mean EI/BMR_{est} than men and EI/BMR_{est} decreased significantly ($P<0.05$) with increasing BMI in both men and women. Although measured BMR increases with increasing BMI (Prentice *et al.*, 1996), Heshka *et al.*,. (1993) showed that predictive equations overestimate the resting metabolic rate in obese subjects. Hence, the possible subsequent underestimation of EI/BMR_{est} in obese individuals has important implications for the interpretation of energy underreporting in this group.

The main food group sources of energy are presented in Table 4. The intake of foods and food groups and the number of individuals consuming various foods provide useful data for qualitative food based dietary guidelines (FBDG) (FAO/WHO, 1996). In the development of FBDG, food intakes are compared between those with different intakes of a target nutrient to determine which foods positively or negatively discriminate toward a diet high or low in that nutrient (FAO/WHO, 1998). Differences in food

intakes between underreporters and acceptable reporters have been documented (Johansson *et al.*, 1998; Price *et al.*, 1997; Pryer *et al.*, 1997). Becker *et al* (1999) addressed this issue specifically in relation to FBDG using food intake data from the Kilkenny Health project, which had been collected on 1212 adults by food frequency questionnaire in 1985 and 1991. When each food group was subdivided into a low intake and a high intake group underreporters were either over represented in the low intake group or under represented in the high intake group for many foods. Food intakes in the present study need to be further examined taking lower than expected energy intakes into consideration.

In summary, energy intakes in the Republic of Ireland and Northern Ireland have not changed remarkably in the last 10 to 12 years. There is evidence of underreporting, however, as the mean EI/BMR_{est} was 1.38 and 25% of the population had an EI/BMR_{est} below 1.10. Additional multivariate analysis of these data is required to further identify subgroups in the population reporting lower than expected energy intakes and to evaluate the effect of low energy intakes on the analysis of the consumption of various foods and food groups.

Table 3.1 Mean daily energy intakes (kcal, MJ) and standard deviations (SD) in Irish adults according to sex and age.

Sex	Age Group	*n*	Energy (kcal) Mean (SD)	Energy (MJ) Mean (SD)
Men	18-64 years	662	2632 (730)*	11.0 (3.1)*
	18-35 years	253	2776 (750)*[a]	11.6 (3.1)*[a]
	36-50 years	236	2632 (728)*[a]	11.0 (3.0)*[a]
	51-64 years	173	2421 (653)*[b]	10.1 (2.7)*[b]
Women	18-64 years	717	1826 (484)	7.6 (2.0)
	18-35 years	269	1848 (473)[a]	7.7 (2.0)[a]
	36-50 years	286	1858 (492)[ab]	7.8 (2.1)[ab]
	51-64 years	162	1735 (479)[b]	7.3 (2.0)[b]

*significantly higher energy intakes in men than women $P<0.001$ (t-test) within each age group.

[ab] different superscripts denote significant differences between age groups within each sex $P<0.05$ (ANOVA).

Table 3.2 Mean energy intake/estimated basal metabolic rate (EI/BMR_{est}) and standard deviations (SD) in Irish adults according to sex, age group and body mass index (BMI).

Sex	Age Group	All			Body Mass Index (BMI) categories§								
					BMI ≤ 24.9			BMI 25-29.9			BMI ≥ 30		
		n	Mean	(SD)	*n*	Mean	(SD)	*n*	Mean	(SD)	*n*	Mean	(SD)
All	Total	1369	1.38	(0.40)	566	1.49	$(0.40)^{c}$	513	1.33	$(0.37)^{d}$	233	1.20	$(0.37)^{e}$
Men	18-64 years	655	1.45	(0.42)***	206	1.62	$(0.39)^{c}$***	286	1.41	$(0.40)^{d}$***	122	1.25	$(0.40)^{e}$*
	18-35 years	249	1.50	$(0.42)^{a}$***	109	1.63	$(0.35)^{c}$***	99	1.46	$(0.42)^{d}$***	32	1.29	$(0.50)^{d}$*
	36-50 years	235	1.44	$(0.42)^{ab}$**	58	1.64	$(0.42)^{c}$**	107	1.42	$(0.39)^{d}$***	53	1.26	$(0.39)^{d}$ns
	51-64 years	171	1.36	$(0.39)^{b}$**	39	1.57	$(0.46)^{c}$*	80	1.34	$(0.36)^{d}$ns	37	1.20	$(0.30)^{d}$ns
Women	18-64 years	714	1.31	0.37	360	1.42	$(0.39)^{c}$	227	1.22	$(0.29)^{d}$	111	1.14	$(0.34)^{d}$
	18-35 years	269	1.33	$(0.38)^{a}$	176	1.42	$(0.39)^{c}$	65	1.17	$(0.31)^{d}$	24	1.03	$(0.19)^{e}$
	36-50 years	285	1.34	$(0.37)^{a}$	133	1.45	$(0.38)^{c}$	106	1.22	$(0.29)^{d}$	42	1.24	$(0.33)^{d}$
	51-64 years	160	1.25	$(0.36)^{b}$	51	1.34	$(0.40)^{c}$	56	1.27	$(0.27)^{cd}$	45	1.11	$(0.38)^{d}$

§ Body Mass Index calculated for 1312/1369 respondents for whom weight and height data were available.

*significant differences in EI/BMR_{est} between males and females in same age groups and/or BMI categories (t-test) ***P <0.001,**P <0.01, *P <0.05, ns = not significant.

^{ab} significant differences in EI/BMR_{est} between age groups within each sex P <0.05 (ANOVA) for the full sample (column "All").

^{cde} significant differences in EI/BMR_{est} between BMI categories within each sex and age group P <0.05 (ANOVA) (rows).

Table 3.3 Mean energy intake/estimated basal metabolic rate (EI/BMR_{est}) and standard deviations (SD) in Irish adults according to sex, age group and body mass index (BMI) excluding dieters and the unwell.

Sex	Age Group	All			Body Mass Index (BMI) categories§								
					BMI ≤ 24.9			BMI 25-29.9			BMI ≥ 30		
		n	Mean	(SD)	*n*	Mean	(SD)	*n*	Mean	(SD)	*n*	Mean	(SD)
All	Total	1200	1.42	(0.40)	526	1.52	$(0.40)^{c}$	433	1.37	$(0.37)^{d}$	188	1.24	$(0.37)^{e}$
Men	18-64 years	605	1.48	(0.41)***	201	1.63	$(0.39)^{c}$***	259	1.44	$(0.39)^{d}$***	106	1.29	$(0.38)^{e}$*
	18-35 years	237	1.52	$(0.41)^{a}$***	108	1.63	$(0.36)^{c}$***	93	1.48	$(0.42)^{d}$***	28	1.34	$(0.47)^{d}$**
	36-50 years	218	1.47	$(0.41)^{ab}$*	57	1.65	$(0.42)^{c}$**	99	1.46	$(0.37)^{d}$***	46	1.32	$(0.36)^{d}$ns
	51-64 years	150	1.40	$(0.40)^{b}$*	36	1.61	$(0.45)^{c}$*	67	1.36	$(0.37)^{d}$ns	32	1.21	$(0.30)^{d}$ns
Women	18-64 years	595	1.36	(0.38)	325	1.44	$(0.39)^{c}$	174	1.26	$(0.29)^{d}$	82	1.18	$(0.36)^{d}$
	18-35 years	235	1.36	$(0.39)^{a}$	163	1.44	$(0.39)^{c}$	52	1.21	$(0.31)^{d}$	17	0.96	$(0.15)^{e}$
	36-50 years	234	1.39	$(0.38)^{a}$	119	1.48	$(0.38)^{c}$	82	1.26	$(0.29)^{d}$	30	1.30	$(0.35)^{d}$
	51-64 years	126	1.30	$(0.36)^{a}$	43	1.38	$(0.40)^{c}$	40	1.32	$(0.27)^{c}$	35	1.19	$(0.39)^{c}$

§ Body Mass Index calculated for 1147/1200 respondents for whom weight and height data were available.

*significant differences in EI/BMR_{est} between males and females in same age groups and/or BMI categories (t-test) ***P <0.001,**P <0.01, *P <0.05, ns = not significant.

^{ab} significant differences in EI/BMR_{est} between age groups within each sex P <0.05 (ANOVA) for the full sample (column "All").

^{cde} significant differences in EI/BMR_{est} between BMI categories within each sex and age group P <0.05 (ANOVA) (rows).

Table 3.4 Percentage contribution of 18 food groups to mean daily energy intakes in Irish adults and the percentage consumers (%cons) of each food group according to sex and age group.

Food Groups	All		Men								Women							
			18-64y		18-35y		36-50y		51-64y		18-64y		18-35y		36-50y		51-64y	
	n = 1379		*n = 662*		*n = 253*		*n = 236*		*n = 173*		*n = 717*		*n = 269*		*n =286*		*n = 162*	
	%	% con	%	% con	%	% con	%	% con	%	% con	%	% con	%	% con	%	% con	%	% con
Meat & meat products	16	98	17	99	18	99	17	99	16	98	15	98	15	95	15	100	15	100
Breads & rolls	14	100	14	100	13	100	15	100	16	100	14	99	14	99	14	100	15	99
Potatoes & potato products	11	99	12	100	13	100	12	99	12	100	10	99	11	99	9	99	9	98
Biscuits, cakes, pastries & puddings	9	91	7	88	6	81	8	91	9	93	9	94	7	89	10	97	11	97
Milk & yogurt	7	98	7	99	7	98	7	100	6	99	8	98	7	97	8	989	9	99
Sugars, preserves, confectionery & savoury snacks	7	95	7	96	8	98	6	95	6	94	7	95	8	96	6	95	6	91
Butter, spreading fats & oils	6	97	6	98	5	99	7	99	7	98	6	96	5	95	6	95	7	97
Alcoholic beverages	5	65	6	70	7	74	5	68	6	66	3	61	4	70	3	64	1	39
Breakfast cereals	4	73	3	72	3	70	4	77	4	71	4	74	4	71	4	75	5	75
Vegetables & vegetable dishes including pulses	4	99	4	99	3	99	4	100	3	100	5	99	5	99	5	100	4	100
Fruit, fruit juice, nuts & seeds, herbs & spices	3	86	3	82	2	80	3	83	3	84	4	89	3	89	4	91	4	89
Flours, grains, starches, rice, pasta & savouries	3	76	3	73	4	80	3	74	2	61	3	80	4	85	4	84	2	61
Cheese	2	74	2	72	2	73	2	74	2	67	2	76	2	78	2	78	2	70
Eggs & egg dishes	2	72	2	77	1	73	2	79	2	80	2	68	2	65	2	71	2	69
Fish & fish dishes	2	68	2	71	2	65	2	72	2	78	2	66	2	57	3	70	3	72
Non-alcoholic beverages	2	100	2	99	3	100	1	99	1	99	2	100	3	100	1	100	1	99
Soups, sauces & miscellaneous foods	2	97	2	97	2	96	1	97	1	97	2	98	2	99	2	98	2	95
Creams, ice creams & chilled desserts	1	58	1	55	1	48	1	59	2	62	1	61	2	56	2	66	2	62
Total %	100		100		100		100		100		100		100		100		100	
Mean daily energy intake (MJ)			11.0		11.6		11.0		10.1		7.6		7.7		7.8		7.3	

% con = percentage consumers.

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Chapter 4

Generation of Estimated Physical Activity Levels (ePALs) from a Physical Activity Questionnaire in Irish Adults

4.1 Introduction

Physical activity data are collected in food intake surveys to provide a comprehensive picture of the health status of the population. Physical activity data can be expressed as a physical activity level (PAL), which is the ratio of total energy expenditure to basal metabolic rate (BMR) EI/BMR (Department of Health, U.K., 1991). PAL is a concise term to describe energy expenditure in a population. Furthermore, physical activity levels are used to identify energy underreporters, using the approach of Goldberg *et al.*, (1991), where energy intake is also expressed as a ratio of BMR (EI/BMR) and compared to a physical activity level for that individual.

Expressing energy expenditure as PALs is a convenient way of controlling for age, sex and body weight. It thereby allows energy expenditure in different groups to be compared. The concept of using PALs was introduced by FAO/WHO/UNU (1985) in describing energy requirements. Previously energy requirements had been estimated on the basis of energy intakes rather than on energy expenditure. It is now, however, well recognised that reported energy intakes may not be valid (Livingstone & Black, 2003) and that intakes may be above or below the energy required to maintain a healthy body weight. FAO/WHO/UNU (1985) described energy requirements according to whether work activity was light, moderate or heavy and used the PALs 1.55, 1.78 and 2.10 in men, and 1.56, 1.64 and 1.82 in women to describe these three categories of activity. These PALs were calculated using the factorial approach where the energy costs of sleep, work, 'discretionary' activities and residual time were expressed as multiples of BMR and subsequently added according to the length of time per day at each activity. Of these four components of activity, the greatest variation in energy expenditure was between types of work. The authors subsequently described the recommended energy requirements according to work activity. The FAO/WHO/UNU (1985) PALs have formed the basis of recommended energy intakes in the U.K., Ireland and Europe.

In 1991, the Department of Health (U.K.) report 'Dietary Reference Values for Food Energy and Nutrients for the United Kingdom' included a matrix of PALs describing energy requirements in men and women at three levels of both 'occupational' (light, moderate and moderate/heavy) and 'non-occupational' activity (non-active, moderately active, very active). For example, the recommended energy requirement for men and women in 'light' occupational activity and 'non-active' non-occupational activity is a PAL of 1.4. This compares to a recommended PAL of 1.9 in men and 1.7 in women

with 'moderate/heavy' occupational activity and 'very active' non-occupational activity. The authors recommended that energy requirements in U.K. populations should be taken as a PAL of 1.4 (light activity) in the absence of detailed information on time spent at specific activities in the population and the energy costs of these activities.

The Scientific Committee for Food (1993) report 'Nutrient and Energy Intakes for the European Community' altered the FAO/WHO/UNU (1985) PALs based on an assumed proportion of time spent in light, moderate and heavy work in different age groups. A total of four PALs were presented for men and women in different age groups based on both a 'desirable' body weight (body mass index = 22), with and without 'desirable' activity, and on an actual weight with and without 'desirable' activity. The PALs presented ranged from 1.33 to 1.77. The reasoning behind this approach was that the increase in morbidity and mortality associated with obesity could be avoided if energy intakes and expenditure were matched within a BMI range of 20 to 22. In addition, the 'desirable' activity, required to maintain health, may be absent in many sedentary European populations. In 1999, the Nutrition subcommittee of The Food Safety Authority of Ireland adopted the above EU recommendations for energy intakes for Ireland (Food Safety Authority of Ireland, 1999).

Physical activity levels can also be used in identifying energy underreporters. It is well acknowledged that lower than expected energy intakes are seen in most food intake studies (Macdiarmid & Blundell, 1998). Goldberg *et al.*, (1991) introduced the concept of addressing the validity of energy intakes by comparing energy intakes, expressed as a multiple of BMR (EI/BMR), to energy expenditure (EE), also expressed as a multiple of BMR (EE/BMR i.e. PAL). The authors (Goldberg *et al.*, 1991) developed an equation that calculated cut-offs for EI/BMR below which energy intakes were not considered valid. These cut-offs were the 95% confidence limit of agreement between EI/BMR and a PAL of 1.55 taking into account the variations found in measuring both energy intake and energy expenditure. The PAL of 1.55 used by Goldberg *et al.*, (1991) was the FAO/WHO/UNU (1985) value for light activity for both men and women. It was chosen in the absence of further information on the physical activity levels in populations at that time and acknowledged as a conservative estimate of energy expenditure. In 1996, Black *et al.*, published physical activity levels from the combined results of all doubly labelled water measures of energy expenditure in adults available, and showed a mean PAL of 1.69 in women and 1.79 in men. In 2000, Black showed

that using a PAL of 1.55 in the Goldberg equation identified only 50% of underreporters while 70% of energy underreporters were identified when population-specific physical activity levels were used (Black, 2000a).

In the North/South Ireland Food Consumption Survey (NSIFCS) self-reported physical activity over the previous was collected by a self-administered physical activity questionnaire addressing activity at home, work and in recreation. This chapter describes the methodology used to generate an estimated physical activity level for individual respondents using the physical activity questionnaire data. In addition, mean ePALs are presented for men and women according to age group and body weight status. The ePALs generated will be used in subsequent work in this thesis to identify energy underreporters using the Goldberg equation to calculate cut-offs for EI/BMR (Goldberg *et al.*, 1991; Black 2000b).

4.2 Methods

4.2.1 The North/South Ireland Food Consumption Survey

The North/South Ireland Food Consumption Survey (NSIFCS) was a cross sectional survey of a random sample of the adult population, aged 18 to 64 years, in the Republic of Ireland and Northern Ireland (n = 1379). The sampling frame used was the electoral register in both areas. The primary objective of the survey was to collect habitual food and drink intakes, in a representative sample of Irish adults, using a 7-day food diary. During the week of food intake recording the respondents completed a series of questionnaires on health and lifestyle, occupation and social class, attitudes towards food and restrained eating and a specific questionnaire on physical activity (Irish Universities Nutrition Alliance, 2001).

4.2.2 Body weight and the prediction of Basal Metabolic Rate

Body weight was measured at the beginning of the survey using a Seca 770 personal weighing scales (CMS Weighing Ltd., London) to the nearest 0.1kg. Each respondent was weighed after voiding and while wearing light indoor clothes and no shoes. Basal Metabolic Rate (BMR) was estimated in 18-59 years olds using the Schofield equations (Schofield *et al.*, 1985) and, in those aged 60-64 years, by the equations used in the 1991 U.K. Dietary Reference Values (Department of Health, U.K., 1991).

4.2.3 Physical Activity Questionnaire

A self-administered questionnaire collected information on physical activity over the previous year in survey respondents. This questionnaire was designed by The Institute of Public Health at the University of Cambridge (Appendix I). It consisted of three sections: home, work and recreation.

In the home section, questions were asked on time asleep, getting about by walking and cycling, time watching TV/video, stair climbing and time spent at seven household activities: (i) food preparation, (ii) food shopping, (iii) other shopping, (iv) cleaning, (v) laundry and ironing, (vi) caring for children and (vii) caring for other persons in the home.

In the work section, questions were asked on up to three jobs held in the past year. The number of hours per week at each job and the number of months worked at each job in the past year were asked. The time spent at each job was then divided into 9 categories of activity representing work at varying intensities while sitting, standing or walking. These categories of activity had been derived during the development of the questionnaire when questions on activity at work were open-ended (Wareham *et al.*, 2002). Respondents could also describe 'other' activities at work, additional to those listed on the questionnaire, and specify the number of hours/week spent at these 'other' activities. Information was also collected on stair/ladder climbing at work and kneeling and squatting at work. Respondents were also asked about the means of travel to work, the distance to work and the frequency of travel to work. The questions on occupational activity were derived from the Modified Tecumseh Occupational Activity Questionnaire, which was validated by Ainsworth *et al.*, (1993a).

In the recreation section, respondents were asked about their participation in 36 listed activities over the past year. The frequency and duration of participation in these activities were recorded. The option to include participation in additional activities, not specified in the questionnaire, was also provided. The 36 activities were listed in order of the frequency with which they were reported in the U.K. population (The Sports Council, 1992). This section was based on the Minnesota Leisure Time Activity Questionnaire (Taylor *et al.*, 1978 and Richardson *et al.*, 1994).

The questionnaire was self-administered during the week of food intake recording. The fieldworker subsequently checked the questionnaire to ensure that all relevant questions had been completed. Fieldworkers assisted respondents who expressed difficulty in completing particular questions in the questionnaire. Data entry was carried out by the fieldworkers using a data entry program provided by the University of Cambridge.

The data were then forwarded to the Institute of Public Health at the University of Cambridge for conversion to metabolic equivalents called METS. All of the analysis described in this paragraph was carried out by the Institute of Public Health. The time spent, per week, at each activity was multiplied by the MET score for that activity. This MET score is the energy cost of the particular activity, expressed as a multiple of resting metabolic rate. One MET score is therefore equivalent to the energy expended while sitting, which is approximately 3.5ml of oxygen per kilogram body weight per minute. The MET scores used by the Institute of Public Health were obtained from the literature (James and Schofield, 1990, Ainsworth *et al.*, 1993b). The energy expended at home, work and recreational activities were calculated separately (home METS, work METS and recreation METS). Home METS described energy expenditure at the 7 household activities listed earlier, but did not include time asleep, getting about by walking or cycling, watching TV/video or stair climbing. Work METS were calculated from the time spent at each of the 9 categories of activity at work and from walking and cycling to work. It did not include travel by car or by public transport to work. Recreation METS described energy expended at all of the listed recreational activities in the questionnaire. The analysed data were returned and presented in an SPSS data file (SPSS Inc., Chicago, IL). The validity of the questionnaire had been measured in 173 individuals in whom energy expenditure was measured by four episodes of four-day heart rate monitoring over 12 months. At the end of the year, these individuals completed the questionnaire. The correlation between recreational and work activity (METS) and energy expenditure was significant at 0.28 (Wareham *et al.*, 2002). Repeatability was high in 399 respondents who completed the questionnaire twice in a three month interval (Wareham *et al.*, 2002). The questionnaire has been used to measure habitual physical activity in over 15,000 adults in the European Prospective Investigation into Cancer (EPIC) cohort in Norfolk, U.K. (Jakes *et al.*, 2003).

4.2.4 Generation of an estimated Physical Activity Level (ePAL)

All of the work described in section 4.2.4 was carried out by the current investigator (denoted by MMcG) to generate an estimated physical activity level (ePAL) from home, work, recreation METS for each respondent who completed the questionnaire. Three approaches were used in the calculation of ePAL.

(i) The validity and accuracy of the answers to all questions in the questionnaire was assessed. Data were adjusted when inaccuracies or inconsistencies were identified.

(ii) The average length of time per day at each activity was calculated to determine the extent to which the physical activity questionnaire accounted for the 24 hours of the day.

(iii) Energy expenditure was calculated for the questions not included in the calculation of home or work METS.

Based on the above adjustments, a value for total energy expenditure was calculated for each respondent, which was subsequently expressed as a physical activity level.

4.2.4.1 Home Activities / 7 Activities in and around the home

Respondents recorded the length of time spent per week at 7 household activities. The activities were:

(i) Preparing food, cooking and washing up.

(ii) Shopping for food and groceries.

(iii) Shopping and browsing in shops for other items (e.g. clothes, toys).

(iv) Cleaning the house.

(v) Doing the laundry and ironing.

(vi) Caring for pre-school children or babies at home (not as paid employment).

(vii) Caring for handicapped, elderly or disabled people at home (not as paid employment).

The answers were close-ended: "none", "less than 1 hour a week", "1 to 3 hours a week", "3 to 6 hours a week", "6 to 10 hours a week", "10 to 15 hours a week" or "more than 15 hours a week". As these answers were close-ended, the answers were accepted as given. There was no answer given to some questions by some respondents, which was coded as missing data by MMcG. This was assumed to mean that no time was spent at that particular activity.

The average number of hours per day spent at these 7 activities was calculated on the basis of these assumptions by MMcG:

"less than 1 hour a week" means 30 minutes a week.

"1 to 3 hours a week" means 2 hours a week.

"3 to 6 hours a week" means 4 hours a week.

"6 to 10 hours a week" means 8 hours a week.

"10 to 15 hours a week" means 12 hours and 30 minutes a week.

">15 hours a week" means 17 hours a week.

The researchers at the Institute of Public Health, University of Cambridge had calculated the total METS per week for these seven activities on the basis of the published MET scores for each activity (Ainsworth *et al.* 1993b). This was called home METS.

4.2.4.2 Home Activities /Getting up and going to bed.

Respondents were asked "at what time do you normally get up?" and "at what time do you normally go to bed?" on weekdays and weekend days separately. Unusual answers were checked against the original questionnaires and data entry errors corrected by MMcG. The time spent in bed/asleep was calculated. Respondents who had not recorded either the time of going to bed or the time of getting up, and who had completed the other sections of the physical activity questionnaire, were allocated eight hours in bed/day as this was the average length of time in bed/asleep for the population. The time spent in bed/asleep (hours/day) was multiplied by a MET score of 0.9 (Ainsworth *et al.*, 1993b).

4.2.4.3 Home Activities / Getting about - Apart from going to work

Respondents were asked to record the "average number of journeys each week" "by bicycle" and "walking" aside from travel to work and recreational cycling and walking. Respondents were asked to record the average distance of each journey under the following categories: "less than 0.5 miles", "0.5 to 1.5 miles", "1.5 to 2.5 miles", "2.5 to 3.5 miles", "3.5 to 5.5 miles" or "more than 5.5 miles". The data were checked to ensure that those who recorded travelling by bicycle and/or walking, in this section, had also recorded the average distance of each journey. The original questionnaire data were consulted as necessary.

The time spent "getting about - apart from travel to work" was calculated for cycling based on the following assumed times for the distances travelled by MMcG.

Cycling less than 0.5 miles takes 5 minutes.

Cycling 0.5 to 1.5 miles takes 10 minutes.

Cycling 1.5 to 2.5 miles takes 20 minutes.

Cycling 2.5 to 3.5 miles takes 30 minutes.

Cycling 3.5 to 5.5 miles takes 45 minutes.

Cycling more than 5.5 miles takes 60 minutes.

The following assumptions were made in calculating the time spent walking, apart from travel to work, by MMcG.

Walking less than 0.5 miles takes 10 minutes.

Walking 0.5 to 1.5 miles takes 15 minutes.

Walking 1.5 to 2.5 miles takes 30 minutes.

Walking 2.5 to 3.5 miles takes 45 minutes.

Walking 3.5 to 5.5 miles takes 75 minutes.

Walking more than 5.5 miles takes 90 minutes.

The average length of time per day (hours/day) spent cycling or walking (apart from recreational activity and travel to work) was calculated on the basis of the above assumed times and the number of journeys per week. Time spent cycling (hours/day) was multiplied by a MET score of 4.0 (Ainsworth *et al.*, 1993b). The MET score of 4.0 is based on an assumed cycling speed of less than 10 miles per hour. This speed is described by Ainsworth *et al.*, (1993b) as 'general cycling, cycling for leisure, cycling to work or cycling for pleasure'. Time spent walking (hours/day) was multiplied by a MET score of 3.5 (Ainsworth *et al.*,1993b). The MET score of 3.5 is based on an assumed walking speed of 3 miles per hour (Ainsworth *et al.*, 1993b).

4.2.4.4 Home Activities / TV or Video Viewing

Respondents were asked about the number of hours of TV or video watched per day "on a weekday before 6pm", "on a weekday after 6pm", "on a weekend day before 6pm" and "on a weekend day after 6pm". The options were close-ended: "none", "less than 1 hour a day", "1 to 2 hours a day", "2 to 3 hours a day", "3 to 4 hours a day" or "more than 4 hours a day". As the answers were close-ended, all answers were accepted as given. The researchers at the Institute of Public Health, University of Cambridge calculated the average number of hours per day watching TV or video over the previous year. Time spent watching TV or video was multiplied by a MET score of 1.0 (Ainsworth *et al.*, 1993b).

4.2.4.5 Home Activities / Stair climbing at home

Respondents were asked about "the number of times that you climb a flight of stairs (approximately 10 steps) each day at home" on weekdays and weekend days. The options given were close-ended: "none", "1 to 5 times a day", "6 to 10 times a day", "11 to 15 times a day", "16 to 20 times a day" or "more than 20 times a day". As the questions were close-ended, all answers were accepted as given. The following assumptions were made in calculating the length of time per day spent stair climbing at home by MMcG:

"1 to 5 times a day" means an average of 3 times a day, which takes 3 minutes.

"6 to 10 times a day" means an average of 8 times a day, which takes 8 minutes.

"11 to 15 times a day" means an average of 13 times a day, which takes 13 minutes.

"16 to 20 times a day" means an average of 18 times a day, which takes 18 minutes.

"more than 20 times a day" means an average of 23 times a day which takes 23 minutes.

Time spent climbing stairs at home (hours/day) was multiplied by a MET value of 8.0 (Ainsworth *et al.*, 1993b).

4.2.4.6 Activity at work / Time spent at work

In this section (4.2.4.6 to 4.2.4.8) the same three approaches were used: (i) the validity and accuracy of all questions asked, (ii) the time accounted for by the activities recorded and (iii) energy expenditure from the activities recorded. Respondents were asked to record details on, a maximum of, three jobs held over the past year. A job was defined as "paid employment" or "regular, organised voluntary work". The questions asked were "name of occupation", "how many hours per week did you usually work?" and "for how many months in the past year did you do this work?" Respondents were then asked to divide the total number of hours worked per week in each job into categories of activity. There were nine named categories of activity on the questionnaire that represented working at different intensities while sitting, standing or walking (Appendix I). Respondents were also able to include time spent at other activities not on the list. Respondents were also asked to record the number of times they climbed a flight of stairs and/or a ladder each day during work. The respondents also recorded if they knelt or squatted at work. Respondents could provide details on three jobs held in the last year and these jobs are referred to as job 1, job 2 and job 3 throughout this chapter. Work METS were calculated at the Institute of Public Health, University of Cambridge using the published MET scores for the categories of activity

at work, stair/ladder climbing and kneeling/squatting at work and travel to work by walking and cycling (Ainsworth *et al.*, 1993b).

The total number of hours recorded as worked per week was compared to the total number of hours entered under the categories of activity at work. This was carried out for job 1, job 2 and job 3. If there was a discrepancy of 1.5 hours or more between the two totals, the original questionnaire data were checked to identify the reasons for the discrepancy. These reasons were classified as follows:

(i) An ambiguity between the total number of hours at work and the total time recorded in the categories of activity at work for no clear reason. In these cases the total hours at work per week was taken as the total hours recorded under the activity categories. This approach was taken as the data in the activity categories at work had been used to calculate work METS.

(ii) Data entry errors. These errors were identified by checking the original questionnaire data. The errors related to either the total number of hours worked per week or the hours entered under the activity categories. The data were corrected.

(iii) Errors in questionnaire completion. These errors were identified when the original questionnaires were checked. The errors were due to respondents completing the time spent per day, instead of per week, at the different work activities or to respondents providing incomplete data. Errors were corrected where possible.

(iv) Breaktimes, which had been included in the total number of hours worked per week and had not been included in the work activity categories. In these cases, the total number of hours worked per week was recalculated to exclude breaktimes.

Respondents recorded the number of months worked in the past year. The aim of the physical activity questionnaire was to describe activity over the past year, meaning the past 12 months. The investigator suspected that some respondents interpreted the "number of months worked in the past year" to mean the current year rather than the previous 12 months. (e.g. a respondent who completed the questionnaire in June and had interpreted the "past year" as the "current year" recorded that they worked six months whereas they may have worked 12 months.) The extent to which this may have happened was investigated as follows. The number of months worked at job 1 was

subtracted from the month of questionnaire completion (i.e. where January = 1, February = 2 and so forth). Respondents with a zero value were identified. There were two situations where a zero value represented a valid response:

(i) If the respondent completed the questionnaire in December and had worked 12 months in the past year.

(ii) If the respondent worked a further number of months at a second or third job.

The investigator also considered the possibility that some questionnaires were completed at the beginning of a month e.g. a respondent who completed the questionnaire at the beginning of July and interpreted the past year as the current year recorded that they worked six months in the past year. These respondents had a -1 value when the number of months worked was subtracted from the month of questionnaire completion (where January = 1, February = 2, March = 3 and so forth). There were two situations where the -1 value represented a valid response to the number of months worked at each job:

1. If the respondent worked 12 months in the past year and completed the questionnaire in November.
2. If the respondent worked an additional number of months at a second and third job.

This procedure was also carried out for job 2 and job 3 as it likely that a respondent interpreted the "past year" similarly for each job (i.e. either interpreted it as the past 12 months or as the number of months worked in the current year). The occupations of those respondents, whom the investigator still considered to have recorded the number of months worked in the current year rather than the past year, were identified. This was necessary as the number of months worked per year may be recorded differently for some jobs e.g. a teacher who has a three month holiday during the summer may record that they worked 9 or 12 months in the past year. In these cases, the investigator increased the number of months worked in the past year to 12 months. After all these considerations, the number of months worked was increased to 12 months in those respondents whom the investigator still considered to have misinterpreted the past year to mean the current year.

After data corrections were made, the time spent at work (hours/day), as an average over the past year, was calculated as follows:

Time spent at job 1 (hours/day) = (((hours per week at job 1) * 4.345)) * ((number of months worked in past year) / 365).

This was repeated for job 2 and job 3 and the total number of hours at work per day calculated.

4.2.4.7 Activity at Work / Time spent travelling to work

Respondents were asked "how many miles is it from home to job 1?" and "how many times a week do you travel from home to job 1?" Respondents were also asked "how do you normally travel to job 1?" The options for means of transport were "by car", "by works or public transport", "by bicycle" or "walking". Respondents recorded whether they travelled by these means of transport "always", "usually", "occasionally" or "never or rarely". These questions were also completed for job 2 and job 3.

The validity of the answers to these questions was checked by initially identifying respondents with extreme answers. Respondents who travelled 45 miles or more to work (single journey) were identified. The original questionnaire data were checked for these respondents and data entry and data coding errors were corrected. Respondents who walked greater than four miles to work were also identified. After checking the original questionnaire data, data entry or data coding errors were corrected. Respondents who didn't record the frequency of travel to work were also identified. The original questionnaire data were checked for these respondents to identify if the frequency of travel to work was omitted at data entry. Otherwise, an estimated frequency of travel to work was given based on the distance travelled, means of travel and hours worked. Respondents who recorded walking /cycling to work more than 10 times per week (i.e. 10 return journeys) were identified. The original questionnaire data were checked and the data were corrected if there were data entry or data coding errors.

The time spent travelling to work was calculated on the basis of the distance travelled, the frequency of travel and means of transport using the following formula:
Time travelling to work (minutes/day) = ((((frequency of travel to job * 2) * 4.345) * number of months worked at job)) * (estimated length of time per journey) / 365.
The frequency of travel was doubled as it referred to the number of return journeys per week. This value was multiplied by 4.345 to determine the number of single journeys to work per month. This was subsequently multiplied by the number of months worked in the past year. This value was multiplied by the duration of each journey and divided by 365 to calculate the average number of minutes spent per day travelling to work in the past year. The duration of a journey to work was required to calculate the average

time spent travelling to work. As this depends on the means of travel used, respondents were categorised according to how they travelled to work. This is presented in Table 4.1.

Table 4.1 Identifying the means of transport to work for respondents who completed the work section of the physical activity questionnaire in the North/South Ireland Food Consumption Survey

Category	**Answer to 'by CAR'**	**Answer to 'by PUBLIC Transport'**	**Answer to by 'BICYCLE'**	**Answer to 'WALKING'**
1. Car only	Always or Usually	Occasionally or Never	Occasionally or Never	Occasionally or Never
2. Bus only	Occasionally or Never	Always or Usually	Occasionally or Never	Occasionally or Never
3. Bike only	Occasionally or Never	Occasionally or Never	Always or Usually	Occasionally or Never
4. Walk only	Occasionally or Never	Occasionally or Never	Occasionally or Never	Always or Usually
5. Car & Walk	Always or Usually	Occasionally or Never	Occasionally or Never	Always or Usually
6. Car & Bus	Always or Usually	Always or Usually	Occasionally or Never	Occasionally or Never
7. Bus & Walk	Occasionally or Never	Always or Usually	Occasionally or Never	Always or Usually
8. Bus & Bike	Occasionally or Never	Always or Usually	Always or Usually	Occasionally or Never
9. Bike and Walk	Occasionally or Never	Occasionally or Never	Always or Usually	Always or Usually
10. Car, Bus & Bike				
11. Car & Bike				
12. Car, Bus and Walk				
13. Car, Bike & Walk				
14. Bus, Bike and Walk				

The categories of travel listed as 10, 11, 12, 13 and 14 in Table 3.2.1 were used to describe respondents who had recorded a combination of means of travel to work and who had not been identified by the other categories of travel to work. This process was repeated for job 2 and job 3.

The estimation of the duration of a journey to work was based on the means of transport.

1. Walking only.

The distances travelled by those who walked to work (for either job 1, job 2 or job 3) were identified and the length of time needed to walk each distance was estimated as follows:

Walking 0.1 miles takes 1.5 minutes.

Walking 0.2 miles takes 3 minutes.

Walking 0.3 miles takes 4.5 minutes.

Walking 0.4 miles takes 7.5 minutes.

Walking 0.8 miles takes 12 minutes.

Walking 1.0 miles takes 15 minutes.

Walking 1.2 miles takes 18 minutes.

Walking 1.3 miles takes 20 minutes.

Walking 1.5 miles takes 23 minutes.

Walking 2.0 miles takes 30 minutes.

Walking 2.5 miles takes 38 minutes.

Walking 3.0 miles takes 45 minutes.

Walking 4.0 miles takes 60 minutes.

2. Cycling only

The distances cycled and the estimated time needed to cycle these distances were as follows:

Cycling 0.5 miles takes 5 minutes.

Cycling 1.0 miles takes 10 minutes.

Cycling 1.5 miles takes 15 minutes.

Cycling 1.8 - 2.0 miles takes 20 minutes.

Cycling 2.4 - 2.5 miles takes 30 minutes.

Cycling 3.0 miles takes 45 minutes.

Cycling 7.0 miles takes 70 minutes.

3. Car or public transport.

The location of residence of each respondent who travelled to work by car or by public transport was identified as this affects the length of time spent travelling to work by car or public transport. Respondents were categorised as living (i) in the open country / a village / a small town (ii) in a medium or large town or (iii) in a city. These categories were chosen as it was assumed that the length of time travelling a journey, of a given distance, would not vary remarkably within each location category. The distance

travelled by these respondents who used a car or public transport to get to work were identified and the estimated times spent travelling are presented in Table 4.2. These times were estimated by the investigator.

Table 4.2 Estimated length of time of each journey to work by car or public transport, according to location of residence, in respondents who completed the work section of the physical activity questionnaire.

	Estimated length of time travelling each distance		
Distance Travelled	Living in open country, village or small town	Living in a medium or large town	Living in a city
0.1 - 1.0 miles	5 minutes	10 minutes	15 minutes
1.1 - 3.0 miles	10 minutes	15 minutes	20 minutes
3.1 - 5.0 miles	15 minutes	20 minutes	30 minutes
5.1 - 7.0 miles	20 minutes	25 minutes	40 minutes
7.1 - 9.0 miles	25 minutes	30 minutes	50 minutes
9.1 - 11.0 miles	30 minutes	35 minutes	60 minutes
11.1 - 13.0 miles	35 minutes	40 minutes	65 minutes
13.1 - 18.0 miles	40 minutes	45 minutes	70 minutes
18.1 - 25.0 miles	45 minutes	55 minutes	80 minutes
25.1 - 30.0 miles	50 minutes	60 minutes	90 minutes
30.1 - 35.0 miles	55 minutes	65 minutes	100 minutes
35.1 - 40.0 miles	60 minutes	70 minutes	110 minutes
40.1 - 45.0 miles	70 minutes	75 minutes	Distance not travelled
45.1 - 60.0 miles	85 minutes	90 minutes	Distance not travelled
70.0 - 75.0 miles	100 minutes	Distance not travelled	Distance not travelled

This was repeated for job 2 and job 3. The length of time spent travelling to work by respondents who recorded a variety of means of transport to work was calculated individually based on the distance travelled, frequency of travel, location of residence and estimated length of time travelling each journey. For example, a respondent who lived in the city and reported travelling 8.0 miles to work, five days a week, by walking and by public transport "always". In this case, the investigator assumed that the respondent walked to the bus / train always. The distance walked was estimated at 1.0 miles / journey and it was assumed that the other 7.0 miles were travelled by public

transport. The average length of time spent travelling to work per day was then calculated.

4.2.4.8 Activity at work / Energy Expenditure

The Institute of Public Health, University of Cambridge, calculated Work METS per week for each respondent. This was calculated from the time spent at the various categories of activity at work and from walking and cycling to work. The number of months worked in the past year was included in this calculation.

The validity of the data entered under the categories of work activities has been addressed in section 4.2.4.6. In brief, there were many reasons identified for the discrepancy between the total number of hours at work and the totalled number of hours entered under the categories of activities. The data were corrected, where possible, and, in some cases, this led to a recalculation of work METS for that person by the investigator.

Similarly, the issue of whether the respondent recorded the number of months worked in the past year (i.e. past 12 months) or in the current year was examined in section 3.2.4.6. As the number of months worked was included in the calculation of Work METS, respondents who the investigator suspected had underestimated the number of months worked, also had a suspected underestimated Work METS. Work METS was recalculated to reflect what the investigator considered "the most likely" number of months worked.

Respondents were able to include "other activities" in the "activity levels at work" section of the questionnaire to describe activities additional to the nine listed categories. As the investigator was unclear if all these activities had been included in the work METS calculation, each respondent who had recorded time spent at "other" activities was identified. Work METS was recalculated for each of these respondents, using the MET scores from Ainsworth *et al.*, (1993b) to determine if the "other" activities had been included. For respondents in whom "other" activities had clearly not been included, the recalculated work METS was accepted.

Work METS, calculated by the Institute of Public Health at the University of Cambridge, included the energy cost of walking and cycling to work. The validity of

the distances travelled and the frequency of travel to work were addressed in section 4.2.4.7. As mentioned in that section, respondents recorded that they travelled by "car", "public transport", "bicycle" and "walking" either "always", "usually", "occasionally" or "never/rarely". In the calculation of work METS at the University of Cambridge, "always" meant 100% of the time, "usually" meant 75% of the time, "occasionally" meant 25% of the time and "never/rarely" meant never. The investigator examined the possibility that work METS may have been under or overestimated due to the reported frequency of travelling to work by more than one means of transport. For example, work METS were overestimated in the respondent who reported travelling 20 miles to work by public transport 'always' and by walking 'always'. The respondent meant that he/she walked to the bus/train for the 20-mile journey to work but the calculation of work METS included walking 20 miles to work and hence, was clearly overestimated. An example of how work METS were possibly underestimated due to travel to work is the respondent who recorded that he/she walked to work 'occasionally' and didn't record another means of travel to work. In this case, the current investigator presumed that the respondent actually walked to work "always" and that work METS was underestimated as "occasionally" represented 25% of the time spent travelling to work. In order to examine the extent to which work METS may have been under or overestimated, due to travel to work, the following respondents were identified: those who mainly walked to work (defined as "always" or "usually"), those who mainly cycled to work (defined as "always" or "usually") and those who recorded walking or cycling to work "occasionally". These respondents were examined individually on the basis of the distance travelled, the frequency of travel and the means of travel used to determine if work METS was correctly estimated or if it was under/over estimated. The investigator considered work METS to be under/over estimated if walking or cycling to work was under/over estimated by one mile or more per working day. Work METS were recalculated for those respondents whom the investigator deemed to have under or over estimated travel to work by walking or cycling. The recalculation for walking was based on an assumed speed of 3.0 miles per hour, which has a MET score of 3.5 (Ainsworth *et al.*, 1993b). The recalculation for cycling was based on an assumed speed of 12 to 14 miles per hour with a MET score of 8. The adjusted work METS took distance travelled, frequency of travel and number of months worked into account.

4.2.4.9 Recreation

In this section, the same three approaches were used: (i) the validity and accuracy of all questions asked, (ii) the time accounted for by the activities recorded and (iii) energy expenditure from the activities recorded. Respondents were asked to record the "average time" spent at 36 recreational activities and the "number of times" that they participated in each activity over the past year. Time spent at each activity was recorded as hours and minutes and the number of times in the past year was recorded as "none", "less than once a month", "once a month", "2 to 3 times a month", "once a week", "2 to 3 times a week", "4 to 5 times a week" or "every day". Respondents who took part in additional recreational activities, not listed in the questionnaire, recorded the name of the activity and the frequency and duration of participation in the last year. Only activities that had a MET score of >1.1 had been used in the calculation of recreation METS. The time spent at seasonal activities was adjusted according to the proportion of the year during which the sport is played. The MET scores for football, rugby and hockey were given a weighting of 0.75 and the MET score for cricket was given a weighting of 0.5. The time (hours/week) spent at recreational activities and recreation METS were calculated at the Institute of Public Health at the University of Cambridge.

The validity of the data in the recreation section of the questionnaire was addressed by identifying if respondents who recorded participating in an activity had recorded both the frequency and duration of participation. The original questionnaires were checked for those respondents, in the data file, who had missing data for either the frequency or the time spent at an activity. The reasons for these incomplete data are as follows. (i) Some respondents had data entry errors, which were corrected. (ii) Other respondents had incomplete data for infrequent activities which, as such, had little influence on both the time spent at recreational activities or the recreational METS. (iii) Other respondents had incomplete data for many activities and were subsequently excluded from this analysis as neither the calculated time spent at recreational activities nor the energy expended at recreation were correct. (iv) Respondents who recorded a high frequency of participation or a high duration of participation in one or more of the listed recreational activities were also identified. The original questionnaire data were checked for these respondents. Data entry errors identified were corrected. One issue was the high frequency of participation in winter sports (i.e. skiing). In the questionnaire, respondents were asked to record the "number of times you did that

activity in the past year". In the case of winter sports, some respondents recorded that they took part in the sport a few times during every week of the previous year. The investigator assumed that this referred to the level of participation during a winter sports holiday. The frequency and duration of skiing was subsequently changed, in these respondents, to represent a two week holiday in the previous year.

4.2.4.10 Changes made to the Physical Activity Questionnaire data

Changes were made to either the time spent at an activity or the METS for that activity in 229 respondents (17% of total). Changes to the time spent at an activity influenced METS e.g. changing the number of months worked in the past year influenced the number of hours worked per day and work METS. In this context, the corrections were made to the aggregated variables (e.g. time spent at an activity and/or METS for that activity) rather than the individual variables in the data file that contributed to these aggregated variables.

4.2.4.11 Accounting for 24 hours per day using the Physical Activity Questionnaire

One of the approaches used in this analysis of the 'apparent' validity of the data recorded in the physical activity questionnaire was to determine the extent to which the questionnaire accounted for the 24 hours in a day. The times spent at each activity (i.e. asleep, getting about, TV/video viewing, stair climbing, 7 household activities, at work, travelling to work and recreation) were summed. If a respondent had less than 24 hours of the day accounted for by these activities, the remaining time was assumed to be sedentary and given a MET score of 1.0 (Ainsworth *et al.*, 1993b). If a respondent had greater than 24 hours accounted for by the questionnaire, the total METS from all activities was adjusted to represent 24 hours. For example, if a respondent had 26 hours accounted for by the questionnaire and their total METS was 45 METS, the adjusted total METS was 41.5 METS ((45METS / 26hours) * 24hours).

4.2.4.12 Calculation of Energy Expenditure and ePAL

The average time per day spent at each activity was multiplied by the relevant MET score, as outlined previously. These new values were summed for all activities to give an overall estimate of MET hours /day (called METS). Total MET hours (METS) reflects both the intensity and duration of all activities in an average day. As one MET hour is the equivalent of resting metabolic rate, total energy expenditure (kcals or MJ/day) at all activities can be calculated by multiplying resting metabolic rate / hour

(kcals or MJ/hour) by the total MET hours. Resting metabolic rate was taken as 10% above predicted basal metabolic rate and expressed as kcals/hour. Total energy expenditure was then divided by basal metabolic rate to calculate an ePAL.

This is an example of the calculation of ePAL for a woman with a resting energy expenditure (RMR) of 70.9kcal/hour. Resting metabolic rate was calculated by multiplying predicted basal metabolic rate by 110%.

	Time/day	MET score for activity	METS per day from activity
Sleep	8.6 hours	0.9	7.74 METS
Walking/Cycling	0.1 hour	3.5	0.35 METS
TV/video viewing	3.3 hours	1.0	3.30 METS
Stair climbing	0.1 hours	8.0	0.80 METS
7 home activities	4.2 hours	Various*	12.1 METS
Work	5.6 hours	Various*	8.77 METS
Travel to work	0.4 hours	1.0 (car)	0.4 METS
Recreation	0.2 hours	Various*	0.58 METS
Time not accounted for by questionnaire	1.5 hours	1.0	1.50 METS
Total	24 hours		35.24 METS

*METS originally calculated by Institute of Public Health, University of Cambridge and recalculated by MMcG according to validity of data in questionnaire.

Total METS x RMR/hour = TEE	35.24 x 70.9 = 2498kcal/day
TEE/BMR = ePAL	2498/1533 = 1.63

4.3 Results

A total of 1348/1379 respondents with a completed physical activity questionnaire and a body weight measurement were included in this analysis initially. Figure 4.1 describes the process by which 1331/1348 respondents were identified as having sufficiently valid data for the calculation of an estimated physical activity level (ePAL). No respondent was excluded on the basis of data provided in the home activities section of the questionnaire (Table 4.1). A total of 11 respondents did, however, require data corrections to calculate the time spent in bed/asleep. Figure 4.2 and Tables 4.4, 4.5. 4.6. 4.7 and 4.8 describe how 14 respondents were excluded from this analysis on the basis

of insufficiently valid data in the 'Activity at Work' section of questionnaire. A further 211 respondents had data corrected to provide a valid estimate of the number of hours spent at work per day and / or the energy expended at work as represented by the work METS. A total of three respondents were excluded from the analysis based on data in the 'recreation' section of the questionnaire (Figure 4.1). A further eight respondents had data corrected from this section to provide a valid length of time/day at recreational activities and estimated energy expenditure in recreation (expressed as recreation METS). (Tables 4.9 and 4.10).

In total, 17 respondents were excluded from this analysis (14 due to invalid data in work section and 3 due to invalid data in recreation section) and data were changed for 229 respondents. In the vast majority of these respondents (211/229 i.e. 82%), data were changed in the 'activity at work' section of the questionnaire. A total of 55% of these changes reflected difficulties that respondents had in completing the 'activity at work' section. A further 25% of these changes were due to data entry errors by fieldworkers and the other 20% of changes reflected difficulties in calculating work METS from the questionnaire. The difficulties in completing the 'activity at work' section of the questionnaire are shown in three ways: actual errors in completing the questionnaire (Table 4.4), the ambiguity between recording the total number of hours worked and dividing this time into activity categories (Table 4.4) and respondents misinterpreting the question on 'the number of months worked in the past year' to mean the current year (Table 4.6). Data entry errors, by fieldworkers, included errors in the total time at work (Table 4.4), errors in the time at different work activities (Table 4.4) and errors in the frequency and duration of travel to work (Table 4.8). In addition the further 20% of data changes were necessary to ensure that all 'other' activities (Table 4.5) were included in the calculation of work METS and to ensure that travel to work by walking or cycling was correctly represented by work METS (Tables 4.7, 4.8)

Overall, a total of 27% of the corrections to the questionnaire data involved altering only the time spent at an activity while 41% of corrections affected only the energy expended at an activity and 32% of corrections affected both the energy expended and the time spent at an activity.

Table 4.11 presents the mean number of hours per day spent at different activities in both men and women. Women spent significantly more time at 'home activities' than

men (3.6hours/day versus 1.2hours/day respectively, $P<0.001$) while men spent more time at work (5.6hours/day) than women (3.1hours/day) ($P<0.001$). Men also spent more time at recreational activities (1.2hours/day) than women (0.7hours/day) ($P<0.001$). Overall, for the total sample (n = 1331), the physical activity questionnaire did not account for a mean number of 4.6 hours per day. The number of hours per day not accounted for by the questionnaire was significantly greater ($P<0.001$) in women (4.9hours/day) than in men (4.3hours/day). The time unaccounted for by the questionnaire was presumed, by the investigator, to be spent at sedentary activities and given a MET score of 1.0. There were however, 95 respondents (7% of the sample) for whom the questionnaire accounted for greater than 24hours per day. The mean (SD) number of hours above 24 hours in these respondents was 1.9 (2.0) hours/day. The median value was 1.1 hours/day (data not shown). As mentioned in the methods section earlier, the mean daily energy expenditure of these 95 respondents was adjusted to represent 24 hours/day (Table 4.2.4.11).

The estimated physical activity levels (energy expenditure/basal metabolic rate) from this analysis are presented in Table 4.12. The mean ePAL for the full sample (n = 1331) was 1.75 with men having a significantly higher ePAL (1.81) than women (1.69) ($P<0.001$; Table 4.13). Men had a higher mean ePALs than women in all age groups (Table 4.13). The distribution of ePAL was normal in men and in women (Figures 4.3a, 4.3b) with a skew to the right in both figures representing those with a high ePALs. The mean ePALs in men and women in each age group were similar to the physical activity levels reported by Black *et al.*, (1996) from doubly labelled water measures of energy expenditure (Table 4.13). Mean ePAL decreased with increasing age in men ($P<0.05$) but not in women (Table 4.13). Mean ePAL did not change significantly with increasing body mass index in either men or women (Table 4.14). In addition, the mean ePALs in normal and overweight men were similar to the doubly labelled water measures of PAL presented by Prentice *et al.*, (1996) for normal and overweight men (Table 4.14). In obese men, however, mean ePAL in the NSIFCS was higher in men with a body mass index (BMI) between 30 and 35 and lower in men with a BMI above 35 compared to the PALs presented by Prentice *et al.*, (1996) for obese men. The sample sizes were small for both the NSIFCS data and the DLW data in very obese men (BMI $\geq$ 35) (Table 4.14). In women, mean ePALs were reasonably similar in all categories of BMI compared to the doubly labelled water measures of PAL for the same BMI categories (Table 4.14).

4.5 Discussion

This is the first time that physical activity data, in a nationally representative sample, have been examined in Ireland to estimate physical activity levels. In generating an estimated physical activity level from a physical activity questionnaire, this analysis used two approaches. In the first place, it addressed the apparent validity of the questionnaire data and, secondly, it addressed the extent to which the questionnaire data accounted for the 24hour day. This analysis addressed the validity of the physical activity data within the framework of checking the completeness of the data, checking whether relevant data matched each other and checking data that appeared implausible. In this context, the vast majority of data from the questionnaires was accepted. It is important to add, however, that this analysis could not address reporting errors outside of the above framework. It is realistic to assume that reporting errors did occur as physical activity, like other self-reported behaviours, is open to selective reporting bias (Lichtman *et al.*, 1992; Norman *et al.*, 2001).

Although some of the methods used in assessing the apparent validity of the data were subjective, they were logical and more efficient than checking all of the data for each individual. The process was time consuming but brought up many important issues relating to the completion of the questionnaire, the data entry methods and the analysis of this questionnaire. To ensure that as many respondents as possible were included in this analysis, the investigator made changes to either the time spent or the energy expended at an activity for 17% of respondents. As the ePALs from this analysis will be used in identifying energy underreporters, it was considered important to include as many respondents as possible as a reduced sample size could alter the prevalence of underreporting in the population. In all, only 17 respondents (1% of the sample) were excluded of which 14 had insufficient data to calculate work METS and 3 had insufficient data to calculate recreation METS.

From this analysis, it is clear that the 'Activity at Work' section of the questionnaire was the most difficult to complete for respondents. In particular, some respondents didn't divide the total number of hours worked into categories of activity and misinterpreted the number of months worked in the past year to mean the current year. Additional written and/or verbal instructions on these issues could reduce the errors that some respondents made in completing the questionnaire.

Data entry errors accounted for 25% of all changes in the 'Activity at Work' section of the questionnaire and were also seen in the 'Home Activities' and 'Recreation' section of the questionnaire. With over 250 fields of data per respondent, data entry errors were likely. Data entry errors were examined in detail, before the current analysis, in advance of forwarding the data to the University of Cambridge for conversion to METS. This involved checking the frequency of the data in all fields for all respondents. Extreme or unusual answers were identified, checked and corrected if necessary. In the current analysis the questionnaires were only checked when the investigator suspected the validity of the data in the database. In other words, it cannot be assumed that all data entry errors have been identified as data that appeared valid to the investigator may actually have been entered incorrectly. To eliminate all data entry errors, each item of data from each physical activity questionnaire could be checked against that entered. The data entry system used was a single entry system where data were entered once. A range of other questionnaire data was collected in the NSIFCS and the customised Questionnaire-Data Entry Program (QDes©) (Tinuviel Software, Warrington, UK) used was a dual entry system where all data were entered twice for validation. Anomalies between the first and second entry, in each data field, were highlighted allowing the fieldworker to confirm which entry was correct. A similar dual entry system may have reduced the data entry errors from the physical activity questionnaire. In addition, the physical activity questionnaire data entry system required that all fields were completed individually for each respondent, irrespective of whether that section of the questionnaire applied to them e.g. if a respondent didn't have a second job, the fieldworker continued to complete all fields relating to job 2, entering '-9' as 'non applicable' and zero where a specific value was required. Changing the data entry system to automatically code 'non applicable' when a series of data entry fields do not apply may reduce data entry errors.

Twenty percent of the changes in the 'Activity at Work' section related to ensuring that the energy expended while walking or cycling was calculated correctly. Walking and/or cycling to work were included in work METS. Respondents could record the frequency of travel to work (by car, public transport, bicycle or walking) as 'always', 'usually', 'occasionally' or 'never', which represented 100%, 75%, 25% and none of the time respectively. Respondents could record an answer for each means of transport to work which, when totalled, according to the percentage of time meant by each answer could be above or below 100%. Many of these answers were valid e.g. if respondent

walked to train station, they recorded that they walked 'always' and took the train 'always'. In the original calculation of work METS, walking the full distance to work was included as respondents were only asked to record the full distance from home to work. In the above example, work METS was clearly overestimated as the distance to work was 20 miles. On the other hand, respondents who recorded that they walked to work occasionally and took the car occasionally, without including any other means of transport, may have underestimated energy expended while travelling to work as occasionally meant 25% of the time. The travel to work section of the questionnaire needs revision to ensure that work METS correctly represents walking and cycling to work.

It is important to consider the impact of these changes on the estimated physical activity level. It is not possible, however, to compare ePAL before and after the changes were made as the original data were presented as METS and not as ePAL. In addition, the ePAL calculated in this analysis included energy expended over the full 24hours, not just at the activities used to calculate the original home, work and recreation METS. As most of the changes were made to the 'Activity at Work' section of the questionnaire, it was possible to determine the impact of these changes on work METS. The impact was small for the full sample as only 16% of respondents had changes made to the work section of the questionnaire. This included 5% of respondents who had changes made to the time spent at work only and 11% of respondents who had changes made to work METS. In these 11% of respondents, work METS changed by a mean (SD) of 33 (37) METS per week. When expressed as a percentage of ePAL, this represented a mean (SD) change of 12% (13). In summary, although the changes made to energy expended at various activities had little impact on overall energy expenditure, it did have a sizeable impact on energy expenditure in the subgroup of the population to which the changes applied.

As ePAL was calculated from total daily energy expenditure, it was necessary to ensure that all activities over 24 hours of the day had been accounted in this analysis. The mean summed time spent at the activities listed in the questionnaire was less than 24 hours at 19.5 hours. It was not surprising that 93% of respondents reported less than 24hours as there were many sedentary/light activities not included in the questionnaire such as driving (aside from travel to work), reading, computer work during leisure and self care. In addition, Wareham *et al.*, (2002), in describing the development of the

questionnaire did not specify that the questionnaire would account for all sedentary activities during the 24 hour day. The missing time in these respondents was subsequently assumed to be sedentary and given an MET score of 1.0. Few physical activity questionnaires have been designed to describe all activities over the 24 hours. Most questionnaires focus on one or more aspects of activity e.g. recreational activity and/or occupational activity (Wareham & Rennie, 1998). Studies using questionnaires, that have attempted to describe all activities over the day, have all reported 'missing time' not accounted for by the questionnaire (Trichopoulou *et al.*, 2001; Norman *et al.*, 2001; Pols *et al.*, 1997) or have simply assumed that all time outside work, recreation or sleep is sedentary (Fogelholm *et al.*, 1996; Arroll *et al.*, 1991). Norman *et al.*, (2001) reported a median of 18.3 hours accounted for by their physical activity questionnaire (range 11.9 - 26.4 hours) while Pols *et al.*, (1997) reported a range of 11 to 27 hours per day from all activities with the majority of respondents reporting between 15 and 20 hours.

A total of 93 respondents (7%) reported greater than 24 hours of activity per day in the physical activity questionnaire with a median of 1.1 hours above 24 in this group. As these respondents spent a greater number of hours at all activities than the full sample (data not shown), it was decided to decrease total energy expenditure proportionately across all activities i.e. corrected daily energy expenditure = uncorrected energy expenditure * (24/number of hours of activity reported). All of the previously mentioned studies adjusted energy expenditure to represent 24 hours of activity. The simplest approach applied a sedentary MET score of 1.0 to unaccounted time, as used in the present study (Fogelholm *et al.*, 1996; Arroll *et al.*, 1991). Other studies increased or decreased energy expenditure proportionately across all activities presuming that the time spent at each activity had been over or underestimated to the same extent (Trichopoulou *et al.*, 2001; Pols *et al.*, 1997). This was the approach used for time above 24 hours in the present study. Norman *et al.*, (2001) used a different approach in adjusting energy expenditure to 24 hours by giving a MET score of 2.0 to both time not accounted for by the questionnaire and time in excess of 24 hours. This was based on the mean of the MET score for self care and walking at home (2.5 MET) and the MET score for sitting (1.5 MET) and the assumption that these types of activities were under or over estimated. A clear implication of assuming that the time accounted for by the questionnaire was sedentary (with a MET score of 1.0) is that ePAL may have been underestimated. This is most relevant in respondents with the lowest summed time

from all activities in the questionnaire in which a large proportion of the day was subsequently presumed to be sedentary e.g. the 10% of respondents with the lowest reported total time of 15.3 hours or less per day were assumed to spend the remaining 8.7 hours at resting metabolic rate. On the other hand, the vast majority of respondents reported between 18 and 24 hours of activity per day. Furthermore, it was most likely that this unreported time was sedentary in the majority of respondents as the questionnaire provided respondents with the opportunity to detail time spent at a variety of recreational, occupational and home-related activities with the facility to add time spent at other activities not listed in the recreation and occupation sections.

On a population level, the mean ePALs are remarkably similar to mean physical activity levels determined from energy expenditure measured by doubly labelled water (Black *et al.*, 1996). In each of the age groups in men and women, the mean ePALs and mean PALs are reasonably comparable. Similarly comparable values for ePAL and PAL was seen when the mean values were compared across BMI categories. This is a relevant finding as one of the recognised limitations of converting METS (expressed as MET hours) to energy expenditure (kcals) by multiplying by body weight is that a resting metabolic rate (RMR) of 1kcal/kg body weight/hour is assumed (Ainsworth *et al.*, 1993b). If the RMR were not equal to 1kcal/kg/hour then energy expenditure will be closely related to body weight. If a RMR of 1kcal/kg/hour had been assumed in this study, the mean ePAL would have been 1.77 in men and 1.76 in women. In addition, these ePALs would have been significantly correlated with body weight ($P< 0.010$) ($r^2 = 0.05$ in men, $r^2 = 0.28$ in women). Furthermore, ePAL, based on an assumed RMR of 1kcal/kg/hour, would have increased significantly with increasing BMI in both men and women. In this study RMR was calculated as BMR multiplied by 1.1. While the mean and median RMR was 1.00, the range was from 0.65 to 1.38. The estimated physical activity levels in this study are not significantly correlated with body weight in either men or women ($P> 0.05$) ($r^2 = 0.005$ in men, $r^2 = 0.002$ in women).

In the majority of respondents, ePAL fell within the boundaries of 1.2 and 2.5, proposed by Black *et al.*, (1996) with ePAL lower than 1.2 in 8 respondents (<1%) and greater than 2.5 in 45 respondents (3%). The lower value of 1.2 was chosen by Black *et al.*, (1996) as it was the average PAL from 4 studies of either chair-bound subjects or non-exercising subjects confined to a calorimeter. In comparison, the 8 subjects in this study, with an ePAL below 1.2, were free-living. They recorded an average of only

14.5 hours of activity per day of which sleep and TV/video viewing occupied 97% of this time at 9.3 hours and 4.8 hours per day respectively. (Indeed one of these respondents recorded no activity other than sleep and watching TV while the others recorded between 10 minutes and 1 hour of activity per day in addition to sleep and TV). These ePALs below 1.2 cannot be considered as valid measurements of activity in free living individuals.

The 10% of the sample with the lowest ePALs had values below 1.37. These 134 respondents certainly appeared more sedentary than the other respondents as they spent more time asleep, more time watching TV, less time at home activities and less time at recreation than the full sample (data not shown). They did however, have fewer hours accounted for by the questionnaire (16.4 hours) than the full sample (19.4 hours). They were also less likely to 'work' with 42% of this group working compared to 81% of the full sample.

It is worth considering the possible reasons why those with the lowest ePALs had less time accounted for by the questionnaire. In the first place, this unaccounted for time may have indeed been sedentary time e.g. reading, driving or computer based activities. It may however be the case that this questionnaire has difficulty in capturing activities outside of work and recreation. Indeed, few questionnaires focus on activities other than occupation and recreation-based activities as these 'other' activities may be diverse and the time spent at them is difficult to quantify as it is not necessarily continuous or specific (Wareham & Rennie, 1998). In the validation of this questionnaire, home METS (based on the time spent at the 7 listed home activities) was negatively correlated with energy expenditure from heart rate monitoring and with work and recreation METS combined. This suggests that those who didn't work or take part in recreational activities either truly had low energy expenditure or that their activities were not fully captured by the questionnaire. In a discussion on physical activity questionnaires, Wareham & Rennie (1998) commented that questionnaires are most effective at measuring easily recalled activities that are intentionally undertaken e.g. swimming, jogging, aerobics. Other less specific activities that are undertaken over less distinct time periods (e.g. activities at home and at work) are difficult to measure by questionnaire (Wareham & Rennie, 1998). It is also possible that these respondents, with the lowest ePALs, had difficulty in completing the questionnaire or were not sufficiently motivated to complete the questionnaire. The NSIFCS was an intensive

study with respondents completing a 7-day food diary and a total of six questionnaires including the physical activity questionnaire. In addition, respondents were visited by a fieldworker on up to four occasions over the survey period.

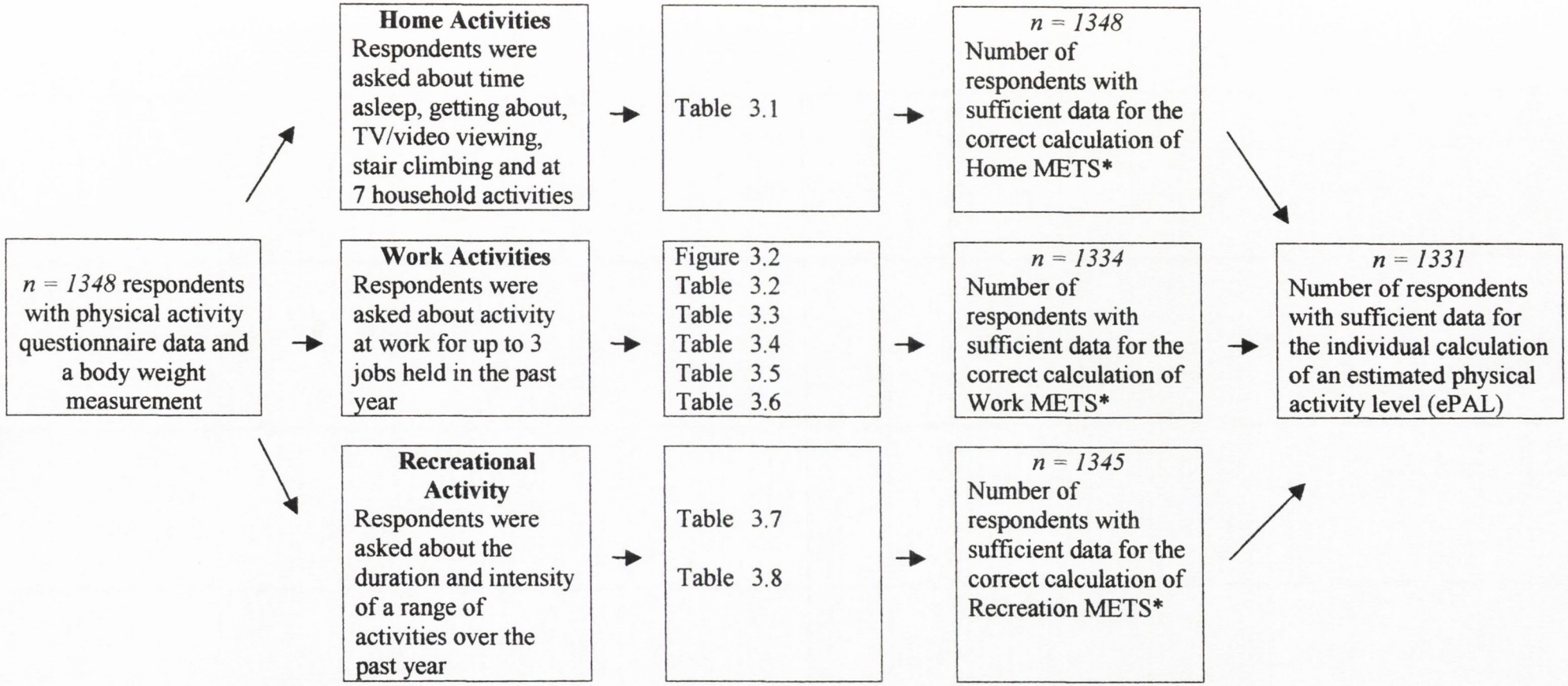
Black *et al.*, (1996) described the upper boundary for PAL of 2.5 as a very physically active lifestyle with PALs above 2.5 unlikely to represent a sustainable way of life. In this analysis, 45 respondents had ePALs above 2.5. The mean ePAL in this sub sample was 2.89. These respondents appear more active than the full sample spending more time at work than the full sample (7.8 hrs/day vs 4.3 hrs/day) and more time in recreation (1.6 hrs/day vs 1.0 hrs/day). Nonetheless, these values above 2.5 are unlikely to describe a consistently active lifestyle and probably represent overreporting of the duration and/or intensity of activities.

Indeed those in the highest percentile of ePAL (> 2.21) spent an average of 3 hours per day more at work than the full sample and 0.5 hours per day more in recreation while spending a similar length of time at all other activities (data not shown). Most of these respondents in the highest percentile of ePAL reporting working (98%) or spending between 2.1 and 16.4 hours at work per day. Interestingly, those in this group who worked more than 10 hours per day (n = 20) also had greater that 24 hours accounted for by the questionnaire. This suggests possible overreporting of the time spent at work by these respondents. When ePAL was adjusted to represent 24 hours (in those who reported greater than 24 hrs of activity), energy expenditure was decreased across all activities according to the length of time spent at that activity. This was based on the assumption that all activities were overreported proportionately. This assumption may not be valid in the case of the respondents mentioned above who reported long working hours. It is interesting to note however that a wide range of ePALs was observed in the 45 respondents who reported more than 24 hours of activity. In addition, these 45 respondents reported longer time at all activities, both active and sedentary, compared to the full sample unlike those with the highest ePALs who reported longer time at work and recreation only.

Overreporting of both the duration and intensity of physical activity has been more widely suggested in the literature than shown. Norman *et al.*, (2001) reported that activity was overestimated by a physical activity questionnaire, compared to activity records, particularly in older adults and in the obese. Lichtman *et al.*, (1992) reported

that activity was overestimated by activity records in obese adults compared to DLW measurements of energy expenditure. Overestimation was greatest in those who underestimated their food intake over the same period (Lichtman *et al.*, 1992).

In conclusion, this analysis showed that the physical activity questionnaire data can be used to calculate estimated physical activity levels (ePALs) that, at a population level, are comparable to doubly labelled water measurements of energy expenditure. In addition, the analysis highlighted (i) aspects of the completion of the physical activity questionnaire, (ii) aspects of data entry and (iii) aspects of data analysis that could be addressed further to improve the use of the questionnaire. The ePALs calculated will be used by the present investigator to identify energy underreporters using the Goldberg equation to calculate cut-offs for EI/BMR. The ePALs calculated can also be used in any further analysis of physical activity and health in this representative sample of the populations of Northern Ireland and the Republic of Ireland.



** The time spent at each activity was multiplied by the MET score for that activity. These values were summed separately for home, work and recreational activities and called Home METS, Work METS and Recreation METS respectively.*

Figure 4.1 The process used to identify respondents, from the North/South Ireland Food Consumption Survey, with complete physical activity questionnaire information for the calculation of an estimated physical activity level (ePAL).

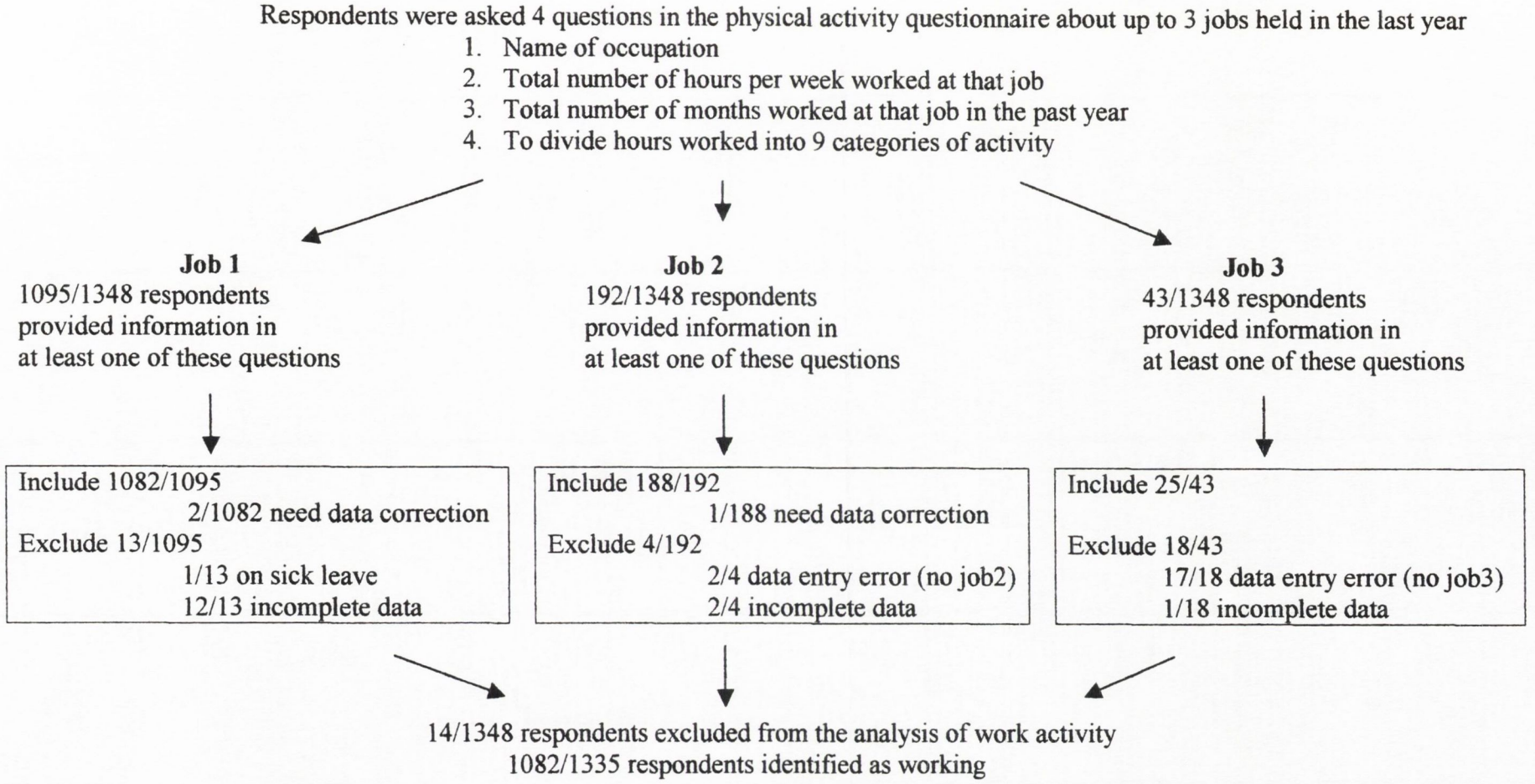


Figure 4.2 Identifying the number of respondents from the North/South Ireland Food Consumption Survey that reported working in the past year and who provided sufficient information, for the calculation of work METS, in the physical activity questionnaire

Table 4.3 Assessing the validity of the data in the 'Home Activities' section of the physical activity questionnaire completed by 1348 respondents in the North/South Ireland Food Consumption Survey.

Number of respondents who answered the relevant question(s)		Were the answers given complete & valid?		Reason for incomplete/invalid data and action taken.
1. Time asleep	n = 1340/1348			Allocated 8hrs sleep for n = 8 respondents with missing data.
		Yes	n = 1337/1340	
		No	n = 3/1340	Data entry error. Correct data and include in analysis.
2. Getting about by				
(a) walking	n = 746/1348	Yes	n = 740/748	
		No	n = 6/748	Incomplete data given. Interpreted as no time spent walking.
(b) cycling	n = 107/ 1348	Yes	n = 107/107	
3. Time watching TV/Video	n = 1328/1348	Yes	n = 1328/1328	
4. Stair climbing	n = 977/1348	Yes	n = 977/977	
5. 7 household activities	n = 1347/1348			n = 1 with missing data. Interpreted as no time spent at any of these activities.
		Yes	n = 1331/1347	
		No	n = 16/1347	n = 16 respondents with missing data for some activities. Interpreted as no time spent at some of these activities.

Table 4.4 Assessing the validity of work METS in 1082 working respondents from the NSIFCS, by comparing the total number of hours worked per week and the total hours recorded in the work activity categories.

Number of respondents with a discrepancy of ≥1.5hours between total hrs worked and total hrs under activity categories	Job 1 111	Job 2 16	Job 3 2	Action
Reasons for discrepancy				
1. Ambiguity in questionnaire data	43/111	7/16		Accept work METS and change total hours to correspond with time in activity categories.
2. Data entry error				
(a) Total hours worked incorrect	9/111	1/16	1/2	Correct data. Work METS will not change.
(b) Time under work activity categories incorrect	36/111	2/16		Correct data and recalculate work METS.
3. Error in questionnaire completion				
(a) Time under activity categories entered per day instead of per week	12/111			Correct data and recalculate work METS.
(b) Incorrect data entered on questionnaire	1/111			Respondent did not work. Work METS = 0.
(c) No time entered under activities		4/16	1/2	Possible to estimate time and recalculate work METS.
(d) Insufficient data	1/111			Exclude from analysis.
4. Breaktimes included in total but not included in categories of activity	9/111	2/16		Change total hours worked to exclude breaktimes. Work METS will not change.

The total number of hours recorded in the categories of activity was subtracted from the total hours worked per week.

Respondents with a discrepancy of ≥ 1.5hours between the two totals were identified.

Table 4.5 Assessing whether 'other' specified activities at work, additional to the nine categories listed in the 'Activity at Work' section of the physical activity questionnaire, had been included in the calculation of work METS in the NSIFCS.

	Job 1	Job 2	Job 3	Action
Number of respondents who recorded 'other' specified work activities	33	3	1	
1. These 'other' activities were included in the calculation of work METS	16	3	0	Accept work METS.
2. These 'other' activities were not included in the calculation of work METS	8	0	0	Recalculate work METS including these 'other' activities.
3. 'Other' activities contributed to less than one hour per day	7	0	1	Accept work METS.
4. Error in questionnaire completion	1	0	0	This issue is dealt with in Table 3.2.
5. Incomplete data on 'other' activity	1	0	0	Accept work METS.

Respondents who recorded 'other' specified work activities were identified.

The researcher assessed whether these 'other' activities had been included in Work METS by recalculating Work METS for each respondent.

Table 4.6 *Assessing the extent to which work METS was underestimated, in working respondents in the NSIFCS, who appear to have misinterpreted the question "for how many months in the past year did you do this work?" to mean the current year rather than the past 12 months.*

Number of respondents who appear to have misinterpreted this question	n = 51/1082	Action
Extent to which work METS appears to have been underestimated:		
by 1 month	n = 17/51	Increase work METS by 8%.
by 2 months	n = 9/51	Increase work METS by 17%.
by 3 months	n = 6/51	Increase work METS by 25%.
by 4 months	n = 4/51	Increase work METS by 33%.
by 5 months	n = 4/51	Increase work METS by 42%.
by 6 months	n = 5/51	Increase work METS by 50%.
by 7 months	n = 0/51	
by 8 months	n = 3/51	Increase work METS by 66%.
by 9 months	n = 2/51	Increase work METS by 75%.
by 10 months	n = 1/51	Increase work METS by 83%.
by 11 months	n = 0/51	

The number of respondents who appeared to misinterpret this question were identified by comparing the number of months worked to the month when the questionnaire was completed (see methods for full details).

Table 4.7 Assessing the validity of the contribution of travel to work, by walking or cycling, to work METS in the NSIFCS.

Respondents recorded whether they travelled to work by car, bus, bicycle or by walking either always, usually, occasionally or never. Work METS, calculated by the Institute of Public Health at the University of Cambridge, included the energy cost of walking and cycling to work. In this analysis, 'always' was 100% of the time, 'usually' was 75% of the time, 'occasionally' was 25% of the time and 'never' was never.

The following approach was taken to identify if work METS correctly represented travel to work by walking and cycling:

1. Respondents who recorded that they walked or cycled to work either mainly (i.e. 'always' or 'usually') or some of the time (i.e. 'occasionally') were identified.

2. These respondents were examined individually, based on the distance to work, the frequency of travel and all means of travel used, to determine if work METS correctly represented travel to work. Work METS was overestimated in those who recorded travelling to work 'always' or 'usually' by a variety of means of transport (see methods for example). Work METS was underestimated in those who reported walking or cycling to work 'occasionally' and didn't record any other means of transport.

3. The investigator considered work METS not representative of travel to work if cycling or walking was under/over estimated by ≥1 mile per working day.

		Job 1	Job 2	Job 3	Action
		n	*n*	*n*	
Number of respondents who travelled some distance to work		*798*	*138*	*20*	
Respondents who recorded that they walked to work mainly		123/798	18/138	3/20	
Did work METS represent travel to work ?	Yes	123/123	17/18	3/3	Accept work METS as representative of travel to work.
	No	0/123	1/18	0/3	Recalculate work METS to represent travel to work.
Respondents who recorded that they cycled to work mainly		37/798	6/138	0/20	
Did work METS represent travel to work ?	Yes	34/37	5/6		Accept work METS as representative of travel to work.
	No	3/37	1/6		Recalculate work METS to represent travel to work.
Respondents who recorded walking/cycling to work sometimes		94/798	18/138	4/20	
Did work METS represent travel to work ?	Yes	65/94	12/18	2/4	Accept work METS as representative of travel to work.
	No	29/94	6/18	2/4	Recalculate work METS to represent travel to work.
Respondents with missing data for means of travel to work		1/798			Data entry error. Correct data & recalculate work METS.

Table 4.8 Assessing the validity of the distances travelled to work and the frequency of travel to work in the NSIFCS.

		Job 1	Job 2	Job 3	Action
		n	*n*	*n*	
Number of respondents who travelled some distance to work		*798*	*138*	*20*	
No of respondents who recorded a frequency of travel to work	Yes	789/798	0	0	
	No	9/798			Assume frequency of travel for these respondents.
No. of respondents who recorded that they walked/cycled > 10 return journeys to work/week		13/798	0	0	
Were these data as entered on the original questionnaire?	Yes	10/13			Accept work METS as representative of travel to work.
	No	3/13			Data coding error. Correct data. Recalculate work METS and time travelling to work.
No. of respondents who walked > 4 miles to work		0/798	1/138		Data coding error. Correct data. Recalculate work METS and time travelling to work.
No. of respondents who travelled >/= 45 miles to work		15/798	4/138	1/20	
Were these data as entered on the original questionnaire?	Yes	12/15	1/4	1/1	Accept work METS as representative of travel to work.
	No	3/15	1/4	0	Data coding error. Correct data. Recalculate work METS and time travelling to work.

Respondents who travelled a long distance to work or who travelled to work frequently were identified.

The original questionnaire data of these respondents were checked to ensure that the data were interpreted correctly.

Table 4.9 Assessing the completeness of the information in the recreation section of the physical activity questionnaire in the NSIFCS.

Number of respondents who recorded information in the recreation section	Were the data provided complete?		Reason	*n*	Action	*n*
n = 1303/1348	Yes	*n* = 1287/1303				
	No	*n* = 16/1303	1.Data entry error	5	Correct data and include in analysis	3
					Respondent didn't partake in any activity (METS =0)	2
			2.Incomplete data for infrequent activity	8	Include in analysis	8
			3.Incomplete data for many activities	3	Exclude from analysis	3

Respondents were asked to record the frequency and duration of participation in 38 named recreational activities over the past year.

Table 4.10 Assessing the validity of data in the recreation section of the physical activity questionnaire in the NSIFCS among respondents who recorded a high frequency of participation and/or a high duration of participation in recreational activities.

Number of respondents who recorded a high frequency or a high duration of activity	Were the data as entered on the questionnaire?	Reason	*n*	Action
n = 32/1303	Yes *n* = 32/32	1. Implausibly high frequency of participation in winter sports	4	Alter frequency of activity to equate to a two-week winter sports holiday/year . Recalculate recreation METS and time spent at recreation.
		2. Error in completion of questionnaire	1	Adjust data. Recalculate recreation METS and time spent in recreation.
		3. Data as entered on questionnaire	27	Accept data and recreation METS.

Respondents were asked about the frequency and duration of participation in 38 named recreational activities over the past year.

Table 4.11 Mean (SD) number of hours per day spent at different activities as assessed by a Physical Activity Questionnaire in 1331 respondents in the North/South Ireland Food Consumption Survey.

	Total (*n* = *1331*)		Men (*n* = *637*)			Women (*n* = *694*)	
	Mean	(SD)	Mean	(SD)		Mean	(SD)
	hrs/day		hrs/day			hrs/day	
Time in bed	8.3	(0.9)	8.1	(0.9)		8.5	(0.9)
Time "getting about" by walking and cycling	0.2	(0.3)	0.2	(0.3)		0.2	(0.3)
Time watching TV/Video	2.6	(1.5)	2.7	(1.4)		2.6	(1.5)
Time stair climbing	0.1	(0.1)	0.1	(0.1)		0.1	(0.1)
Time at 7 home activities	2.4	(2.2)	1.2	(1.3)	***	3.6	(2.2)
Time at work	4.3	(3.0)	5.6	(2.9)	***	3.1	(2.5)
Time travelling to work	0.5	(0.5)	0.6	(0.6)		0.4	(0.4)
Time at recreational activities	1.0	(0.8)	1.2	(1.0)	***	0.7	(0.6)
Time not accounted for by questionnaire	4.6	(3.0)	4.3	(3.1)	***	4.9	(2.9)
Total	24		24			24	

*** Significant difference between men and women in time spent at 7 home activities, time spent at work, time spent in recreation and time not accounted for by questionnaire (t-test / Mann-Whitney test): $P < 0.001$.

Table 4.12 Mean (SD), median and percentiles for estimated physical activity levels (ePAL) for respondents in NSIFCS.

	Total sample	Male	Female
n	*1331*	*637*	*694*
Mean	1.75	1.81	1.69
(SD)	0.36	0.42	0.27
Median	1.68	1.71	1.66
Percentiles			
10	1.38	1.36	1.39
20	1.47	1.46	1.48
25	1.51	1.52	1.50
30	1.55	1.56	1.54
40	1.61	1.64	1.60
50	1.68	1.71	1.66
60	1.75	1.81	1.72
70	1.84	1.95	1.78
75	1.89	2.03	1.82
80	1.98	2.12	1.86
90	2.21	2.37	2.03

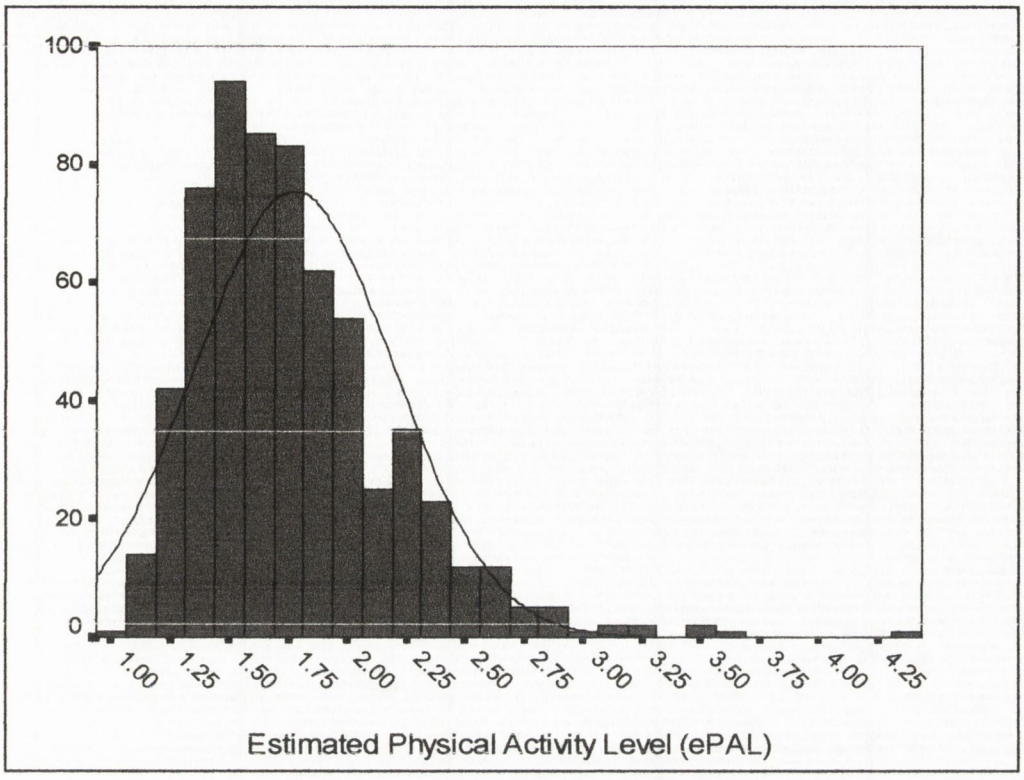


Figure 4.3a Distribution of Estimated Physical Activity Level (ePAL) in 637 men from the North/South Ireland Food Consumption Survey.

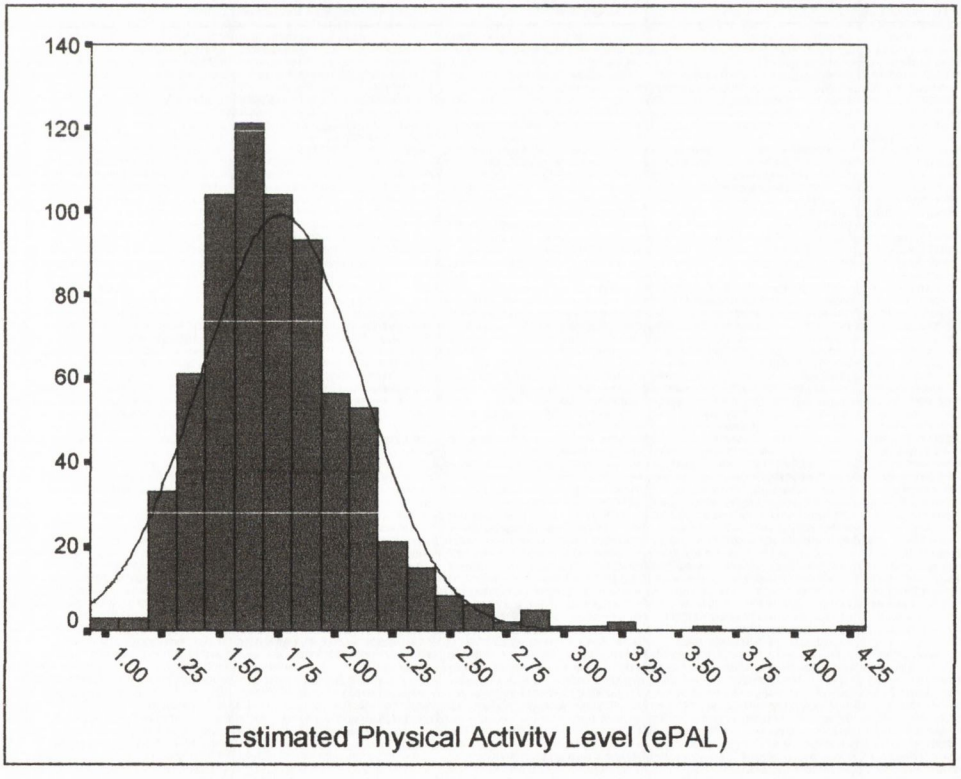


Figure 4.3b Distribution of Estimated Physical Activity Level (ePAL) in 694 women from the North/South Ireland Food Consumption Survey.

Table 4.13 A comparison of Physical Activity Levels (PAL) from doubly labelled water measurements of energy expenditure (Black *et al.*, 1996) and estimated Physical Activity Levels (ePAL) measured by questionnaire in the NSIFCS, according to age.

		Physical Activity Levels (Black *et al.*, 1996) (PAL = TEE/BMR)		Estimated Physical Activity Levels (NSIFCS) (ePAL = TEE/BMR)			
Sex	Age Groups	*n*	Mean (SD)	*n*	Mean (SD)		
Men	18-64 years	107	1.79	637	1.81 (0.42)		***
	18-29 years	56	1.85 (0.33)	156	1.88 (0.46)	[a]	***
	30-39 years	36	1.77 (0.31)	150	1.88 (0.41)	[a]	***
	40-64 years	15	1.64 (0.17)	331	1.74 (0.40)	[b]	*
Women	18-64 years	212	1.69	694	1.69 (0.27)		
	18-29 years	89	1.70 (0.28)	158	1.67 (0.29)	[a]	
	30-39 years	76	1.68 (0.25)	190	1.73 (0.26)	[a]	
	40-64 years	47	1.69 (0.23)	346	1.68 (0.27)	[a]	

Significant differences in ePAL between men and women in same age groups (t-test): *** $P<0.001$, * $P<0.05$.

[ab] Significant differences in ePAL between age groups in each sex. $P<0.05$ (ANOVA).

Table 4.14 A comparison of Physical Activity Levels (PAL) from doubly labelled water measurements of energy expenditure (Prentice *et al.*, 1996) and estimated Physical Activity Levels (ePAL) measured by questionnaire in the NSIFCS, according to Body Mass Index (BMI).

		Physical Activity Levels (Prentice *et al.*, 1996) (PAL = TEE/BMR)		Estimated Physical Activity Levels (NSIFCS)† (ePAL = TEE/BMR)		
Sex	BMI Groups	*n*	Mean (SD)	*n*	Mean (SD)	
Men	BMI ≤ 24.9	72	1.80 (0.32)	198	1.82 (0.39) [a]	***
(18-64y)	BMI = 25-29.9	23	1.86 (0.29)	280	1.81 (0.41) [a]	***
	BMI = 30.0-34.9	4	1.82 (0.29)	97	1.74 (0.42) [a]	ns
	BMI ≥ 35.0	8	1.52 (0.23)	23	1.79 (0.57) [a]	ns
Women	BMI ≤ 24.9	126	1.67 (0.27)	349	1.70 (0.27) [a]	
(18-64y)	BMI = 25-29.9	45	1.73 (0.25)	222	1.66 (0.23) [a]	
	BMI = 30.0-34.9	29	1.73 (0.23)	73	1.73 (0.30) [a]	
	BMI ≥ 35.0	12	1.65 (0.20)	35	1.70 (0.39) [a]	

† n = 1277 respondents with BMI and ePAL measurements.

Significant differences in ePAL between men and women in same BMI categories (t-test): *** $P < 0.001$, ns = non significant.

[a] No significant differences in ePAL between BMI categories in each sex. $P > 0.05$ (ANOVA).

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Chapter 5

Including Physical Activity Data Identifies More Energy Underreporters in the North/South Ireland Food Consumption Survey

5.1 Abstract

Objective: To use estimated physical activity levels (ePALs) in identifying energy underreporters in the NSIFCS using the Goldberg equation and to compare these underreporters with those identified using a PAL of 1.55.

Design: 7 day food diary and physical activity questionnaire.
Setting: Random sample of Irish population.
Subjects: 1331 men and women, aged 18-64y.

Intervention: Physical activity METS converted to total energy expenditure (TEE) ePAL = TEE/BMR. Underreporters identified using 4 approaches to the PAL used in the Goldberg equation. Approach 1 assumed a PAL of 1.55. Approaches 2 and 3 used the FAO/WHO/UNU (1985) PALs for low, medium and high activity and men and women were categorised as low, medium and high activity by their tertile of METS (approach 2) or their ePAL (approach 3). In approach 4, individual ePALs were used.
Results: Approach 1 identified 19% of respondents as underreporters compared to 30%, 29.5% and 31.5% identified by approaches 2, 3 and 4 respectively. Approaches 1 and 3 were subsequently compared. Being female or overweight/obese was independently associated with underreporting for both approaches. Excluding underreporters did not affect the % food energy from macronutrients for both approaches. In contrast, the proportion meeting dietary targets decreased for fat and carbohydrate and increased for iron as more underreporters were identified.

Conclusion: Using population-specific physical activity data is necessary to identify a wider range of underreporters which has an affect on nutrient adequacy in a population.
Descriptors: physical activity, underreporting, energy intake.

5.2 Introduction

Correct associations between diet and health require valid measures of dietary intakes. There is widespread evidence, however, of a bias towards lower than expected reported energy intakes in food intake surveys. The challenge is to identify those subjects with invalid reported energy intakes and this has been addressed in the past decade by the approach of Goldberg *et al.*, (1991) in comparing energy intakes to energy expenditure. Goldberg *et al.*, (1991) used an equation to calculate cut-offs for the ratio of reported energy intake to basal metabolic rate (EI/BMR) below which reported energy intakes were not considered to represent habitual energy intakes. These cut-offs are the lower 95% confidence limits of agreement between EI/BMR and a physical activity level (PAL) of 1.55 and take into account daily variation in energy intakes, precision of estimating basal metabolic rate, within and between-subject variation in energy expenditure, the number of days that food intake was recorded and the number of subjects studied. If the mean EI/BMR value in the population is lower than the cut-off calculated for the full population size, then the study is biased towards energy underreporting. The equation will also identify individual underreporters if the cut-off for EI/BMR is calculated for $n = 1$. Various terms have been used to describe respondents with an EI/BMR less than the relevant cut-off e.g. low energy reporters, underreporters or misreporters. In this paper the term underreporters is used as a generic term to describe those with lower than expected reported energy intakes. It is acknowledged that underreporting food intake is one aspect of low energy intakes while undereating and methodological issues can also contribute to invalid reported energy intakes.

Goldberg and Black (Goldberg *et al.*, 1991; Black *et al.*, 1991; 1997; Black, 2000a; 2000b) have repeatedly acknowledged the limitations of using a PAL of 1.55, in identifying underreporters, as it represents sedentary activity as defined by FAO/WHO/UNU (1985). This PAL was originally used by Goldberg *et al.*, (1991) in the absence of other information on physical activity in free living populations. The authors acknowledged that if the mean PAL value of a population is greater than 1.55 then the proportion of the population identified as having invalid energy intakes will be underestimated. Black *et al.*, (1996) subsequently published physical activity levels from 574 individuals with energy expenditure (EE) measured by doubly labelled water (PAL = EE/BMR) and found mean PAL values of 1.79 and 1.69 for men and women aged 18-64 years respectively (n = 319). This represented all doubly labelled water

measures of total energy expenditure, published and unpublished, available to the authors at that time. Interestingly, the mean PAL in all adult age groups, with the exception of those aged over 75 years, was greater than 1.55.

More recently, Black (2000a) showed that the Goldberg cut-offs (Goldberg *et al.*, 1991), based on a PAL of 1.55, identified only 50% of 'true' underreporters. These 'true' underreporters were identified by the direct comparison of reported energy intake to energy expenditure, as measured by doubly labelled water. This was, again, based on the 95% confidence limit of expected agreement between EI and EE. Respondents were then divided into three categories of activity (low, medium and high) based on the FAO/WHO/UNU (1985) PALs recommended to describe low, medium and high activity for men (1.55, 1.78, 2.10) and for women (1.56, 1.64, 1.82). The cut-offs were recalculated using these PAL values and over 70% of the 'true' underreporters were identified. Black (2000a) concluded that information on each individual's physical activity is necessary to identify energy intakes of poor validity using the Goldberg cut-offs for EI/BMR.

In this paper estimated physical activity levels (ePALs) are presented from the North/South Ireland Food Consumption Survey (NSIFCS) and these data are subsequently used to identify underreporters using four approaches to selecting PALs for use in the Goldberg equation. This provided a unique opportunity to investigate if the main characteristics associated with underreporters are consistent when different PALs are used to identify energy underreporters. In addition, the rigorous examination of underreporting in this study was extended to evaluate its impact on the interpretation of energy and nutrient intakes and the subsequent implications for evaluating targets for public health nutrition.

5.3 Methods

The North/South Ireland Food Consumption Survey (NSIFCS) was a cross sectional survey of 1379 adults randomly selected from the populations of the Republic of Ireland and Northern Ireland. A detailed description of the survey design and sampling procedures has been published by Kiely *et al.*, (2001).

5.3.1 Food Intakes

A 7 day food diary was completed by each respondent. Harrington *et al.*, (2001) has described in detail the protocol followed. In summary, respondents recorded a description of each item of food or drink taken over seven days. The amount of the item was also recorded and, if applicable, the brand name and cooking method used. In addition, details were recorded on the ingredients in composite dishes. Each respondent was visited on up to 4 occasions during the food diary recording week, by the same fieldworker, to quantify the foods/drinks recorded and to ensure that the diary was complete. A series of methods was used to quantify foods and drinks recorded which included: fieldworkers weighing replicates of foods and drinks eaten by the respondent, a photographic food atlas, manufacturer's data and household measures. Fieldworkers encouraged respondents to continue their normal eating pattern during the survey. Food and drink intakes were analysed for energy and nutrients using WISP © (Weighed Intake Software Program. Tinuviel Software, Warrington, U.K.). This nutrient analysis program is based on McCance and Widdowson's 'The Composition of Foods' (Holland *et al.*, 1995) and published supplements (Holland *et al.*, 1988; Holland *et al.*, 1989; Holland *et al.*, 1991; Holland *et al.*, 1992; Holland *et al.*, 1993; Chan *et al.*, 1994; Chan *et al.*, 1995; Chan *et al.*, 1996; Holland *et al.*, 1996). The nutrient composition database was expanded to include 860 additional foods or dishes eaten by the respondents in this survey.

5.3.2 Weight, height and estimated Basal Metabolic Rate (BMR_{est})

Body weight was measured at the beginning of the survey using a Seca 770 weighing scales (CMS Weighing Ltd. U.K.) to the nearest 0.1kg and height was measured using the Leicester portable height measure (CMS Weighing Ltd., U.K.). Body Mass Index was calculated as Weight (kg)/Height (M^2). Basal Metabolic Rate (BMR) was estimated in 18-59 year olds using the Schofield equations (Schofield *et al.*, 1985) and by the equations used in the 1991 U.K. Dietary Reference Values for those aged 60-64 years (Department of Health, U.K. 1991). Energy intakes were expressed as a ratio of estimated BMR (EI/BMR_{est}).

5.3.4 Physical Activity Questionnaire and the estimated Physical Activity Levels (ePAL)

Respondents completed a self-administered physical activity questionnaire, which measured activity over the previous year. The questionnaire was designed by the

Institute of Public Health at the University of Cambridge, U.K. and comprised of three sections: home, work and recreation. In the home section, questions were asked on time asleep, time spent getting about by walking and cycling, time watching TV/video, stair climbing and time spent at many household activities: food preparation and associated work, shopping, cleaning, laundry, ironing, caring for children and caring for other persons in the home. In the work section, questions were asked on up to three jobs held in the past year. Respondents were asked the number of hours per week at each job and the number of months worked at each job in the past year. The time spent at each job was then divided into 9 categories of activity representing work at varying intensities while sitting, standing or walking. These categories of activity had been derived during the development of the questionnaire when questions on work activity were open-ended (Wareham *et al.*, 2002). The option to enter time spent at 'other' specified activities was available. Information was also collected on stair/ladder climbing at work and kneeling and squatting at work. Respondents were asked about the means of travel to work, the distance to work and the frequency of travel to work. In the recreation section, respondents were asked about their participation in 36 listed activities over the past year. The frequency and duration of participation in these activities were recorded. The option to include participation in additional open-ended activities, not specified in the questionnaire, was also provided.

Data were entered by fieldworkers using a data entry program provided by the Institute of Public Health, University of Cambridge. The data were then converted to MET hours by multiplying the time spent at an activity by the MET score for that activity. A MET score is the energy cost of a particular activity expressed as a multiple of resting metabolic rate. A MET score of one is equivalent to the energy expended while sitting which is approximately 3.5mls of oxygen per kilogram body weight per minute (Ainsworth *et al.*, 1993). The MET scores used in this analysis were obtained from the literature (James & Schofield, 1990; Ainsworth *et al.*, 1993). The MET hours per day at home, work and recreation were calculated and summed to give an overall value called total METS. A total of 1348 respondents, who had a body weight measurement, completed the physical activity questionnaire. All of the above analyses was completed at the Institute of Public Health, University of Cambridge.

The physical activity data were further examined by the present author for the calculation of an estimated Physical Activity Level (ePAL) for each respondent. The

author assessed the apparent validity and accuracy of the answers given to each question in the questionnaire for each respondent. Unusual or unexpected answers were identified (e.g. high frequency or high duration of an activity). Data entry errors and errors in the completion of the questionnaire were identified and the relevant corrections were made to both the time spent at the activity and the METS for that activity. Ambiguous or conflicting answers were also identified (e.g. difference between the total number of hours at work and the summed number of hours entered under the different types of activity at work). The most likely answer was accepted and, as above, the relevant adjustment was made to the time spent at the activity and the METS for that activity. A small proportion of respondents (n = 17/1348) were excluded from this analysis due to incomplete physical activity data. Of the remaining 1331 respondents included in the analysis, 229 (17%) had changes made to the time spent at an activity and the METS for that activity. Activities which had not been included in the calculation of total METS (e.g. time asleep, time watching TV, time spent travelling by car or bus) were given an appropriate MET score (Ainsworth *et al.*, 1993) which was multiplied by the length of time spent per day at the activity for each respondent. The author also calculated the time spent at each activity listed in the questionnaire to determine the extent to which the questionnaire accounted for the 24 hours of the day. In respondents where the total time was less than 24 hours, the remaining time was assumed to be sedentary. In respondents where the total time was greater than 24 hours (n = 95), the total METS was adjusted proportionately across all activities to represent 24 hours.

For each respondent, the adjusted total METS was multiplied by resting metabolic rate (RMR), expressed as kcals/hour to calculate energy expenditure (kcals) (Ainsworth *et al.*, 1993). In this study, RMR was taken as BMR multiplied by 1.1. Energy expenditure was subsequently divided by BMR to generate a subject-specific estimated Physical Activity Level (ePAL) for each of the 1331 respondents.

5.3.5 Identification of Underreporters

The Goldberg equation (Goldberg *et al.*, 1991; Black, 2000b) was used to identify underreporters using four approaches, which differed in the physical actvity level(s) used in the equation. For each approach, underreporters were respondents with an EI/BMR_{est} below the calculated cut-offs. The calculation of this equation is clearly described by Black (2000b). Approach 1 followed the original use of the Goldberg

equation where a PAL of 1.55 was assumed for each respondent. In approach 2, men and women were divided in tertiles of total METS called low, medium and high activity. The FAO/WHO/UNU (1985) physical activity levels describing low, medium and high activity were applied to these categories (Men: 1.55, 1.78, 2.10. Women: 1.56, 1.64, 1.82) and used in the Goldberg equation to calculate cut-offs for EI/BMR_{est}. A total of six different cut-offs were calculated using approach 2. In approach 3, men and women were classified as being of low, medium or high activity according to their individual ePALs. The FAO/WHO/UNU (1985) PALs defined these categories. In men, low activity was defined as an ePAL < 1.665, medium activity as an ePAL of 1.665 to 1.94 and high activity as an ePAL > 1.94. In women, low activity was defined as an ePAL < 1.60, medium activity as an ePAL of 1.60 to 1.715 and high activity as an ePAL > 1.715. The mid-points of the above categories are the FAO/WHO/UNU (1985) physical activity levels for low, medium and high activity in men and women. These FAO/WHO/UNU (1985) PALs were used in the calculation of the Goldberg cut-offs for EI/BMR_{est} in approach 3. These cut-offs are the same as for approach 2 but approaches 2 and 3 differ in the way in which respondents were categorised as low, medium or high activity. In approach 4, each individual's ePAL was included in the Goldberg equation to calculate a cut-off for EI/BMR_{est} for each individual. The number of respondents identified as energy underreporters by each of the four approaches is presented for the full population and for men and women in three age categories.

5.3.6 Statistical Analysis

Statistical analysis was performed using SPSS ® (version 10.0, SPSS Inc., Chicago, IL). Mean (SD) ePALs were calculated for men and women. Independent t-tests were used to compare mean ePALs between men and women within age and BMI categories. A one-way analysis of variance was used to test for differences in ePAL between age and BMI categories with a Scheffe post hoc test when groups had equal variances or the Tamhane post hoc test when groups had unequal variances (Coakes & Steed, 1999). Chi-squared analysis was used to test for differences in the proportion of men and women identified as underreporters using each approach and the difference in the proportion of underreporters in each age group for each approach. Mean BMI values were compared between underreporters and valid reporters using independent t-tests. Logistic regression analysis was carried out to determine the independent associations between sex, BMI, age and underreporting where being an underreporter (by approach 1 and approach 3 separately) was used as the dependent variable and sex, BMI and age

group were the independent variables. Mean (SD) intakes of macronutrients and three micronutrients (calcium, iron and vitamin C, including supplements) were calculated both as absolute intakes and intakes expressed as a percentage of energy (macronutrients) or as intakes/10MJ (micronutrients). Independent t-tests were used to compare these nutrient intakes between underreporters and others (called valid reporters) for each approach. Vitamin C and iron intakes were log transformed before this analysis. Alcohol intakes were not normally distributed and non parametric tests were used to compare intakes in underreporters and valid reporters. For all analysis, significance was defined as $P<0.05$.

5.4 Results

The mean ePAL was 1.81 in men and 1.69 in women while the median values were 1.71 and 1.66 respectively (Table 5.1). The distribution of ePAL was normal in both men and women with a skew to the right representing a small number of individuals with high ePALs. The ePALs are compared to physical activity levels (PALs) from doubly labelled water measurements of energy expenditure (n = 319) (Black *et al.*, 1996) in Table 5.2. The mean ePAL in men and women (1.81, 1.69) was remarkably comparable to the mean PAL in men and women reported by Black *et al.*, (1996) (1.79, 1.69). Reasonably comparable ePALs and PALs, from doubly labelled water measurements, were seen in the different age groups (Table 5.2). In the NSIFCS, men had significantly higher ePALs than women in all age groups with the greatest difference seen in those below 40 years of age ($P<0.001$). The estimated Physical Activity Levels did not vary significantly with age in women while mean ePAL was significantly lower in 40-64 year old men than in men aged 18-39 years ($P<0.05$) (Table 5.2). Mean ePALs are compared to doubly labelled water measurements of physical activity in each BMI category in Table 5.3. These Physical Activity Levels are from the same 319 individuals as in Table 5.2 (Prentice *et al.*, 1996). The mean ePALs and PALs were very similar in the lower BMI categories in men and in all BMI categories in women (Table 5.3). In the NSIFCS, mean ePALs did not differ significantly ($P>0.05$) between BMI categories in either men or women (Table 5.3). The higher ePALs seen in men compared to women in each age group (Table 5.2) is also seen in the lower BMI categories ($P<0.001$) but not in the obese BMI categories (Table 5.3).

The number of respondents identified as energy underreporters by each of the four approaches is presented for the full population and for men and women in three age

groups (Table 5.4). A total of 19% of the population were identified as underreporters using a blanket cut-off for EI/BMR_{est} of 1.05 (approach 1) while 30% were identified using approach 2, 29.5% using approach 3 and 31.5% using approach 4 (Table 5.4). A significantly ($P<0.05$) higher proportion of women than men was identified as underreporters using all four approaches for all ages combined. This difference was not consistently significant, however, in each of the three age groups (Table 5.4).

The men and women identified as underreporters by approach 1 (i.e. using the 1.05 cut-off for EI/BMR_{est} represented the lower end of the range of reported energy intakes and were subsequently classified as underreporters by approaches 2 and 3. The vast majority of this group was also classified as underreporters using approach 4. Approaches 2 and 3 identified virtually the same underreporters. This was due to the fact that categorising respondents as low, medium and high activity using tertiles of total METS was remarkably comparable to dividing men and women into low, medium and high activity categories using the FAO/WHO/UNU (1985) physical activity levels as described in the methods. In total, 86% of men and 87% of women were classified in the same tertiles of total METS (Approach 2) and category of activity (e.g. being in the lowest tertile for total METS and the low activity category). The remaining 14% of men and 13% of women were classified in 'neighbouring' categories (e.g. being in the middle tertile for total METS and the high/low activity category). The vast majority of underreporters identified by approaches 1, 2, or 3 were also identified by approach 4 with only 34 respondents classified as underreporters by approach 4 who were not identified by any of the other approaches (1% of all underreporters identified by approach 4).

From this point onwards, the results are a comparison of underreporters identified by approach 1 and the greater number identified by approach 3. For all ages (18-64years), there was a significantly ($P<0.05$) greater number of women underreporters than men underreporters identified by each of the approaches used (Table 5.4). The level of significance decreased as the number of underreporters increased e.g. $P<0.001$ (approach 1) and $P<0.01$ (approach 3) (Table 5.4). In each age group a higher proportion of women were underreporters compared to men. This was not, however, a consistently significant difference (Table 5.4). Interestingly, the increase in the proportion of men identified as underreporters, between approach 1 and approach 3, was greater than that seen in women (1.66 fold increase in men underreporters, from

15% (approach 1) to 25% (approach 3), compared to a 1.44 fold increase in women underreporters, from 23% (approach 1) to 33% (approach 3)).

There was no significant ($P>0.05$) difference in the mean age of underreporters compared to others using any of the approaches (data not shown). In general, there was a non significant increase in the proportion of underreporters identified with increasing age by each approach (data not shown).

The mean BMI of underreporters was significantly higher ($P<0.001$) than the mean BMI of those reporting valid energy intakes using each of the four approaches (data not shown). A greater proportion of overweight and obese respondents were underreporters than normal weight respondents. This was true for both men and women. Using approach 1, 14% of normal weight women were underreporters compared to 28% of overweight women and 45% of obese women. Using approach 3, 22% of normal weight women were underreporters compared to 41% of overweight and 57% of obese women. An identical pattern was seen in men where, using approach 1, 5% of normal weight men were underreporters compared to 17% of overweight and 29% of obese men. Using approach 3, 13% of normal weight men were underreporters in comparison to 28% of overweight and 38% of obese men.

Logistic regression analysis showed that the odds ratio of being an underreporter (approach 1) was 2.20 times greater in women than in men ($P<0.001$. 95% CI: 1.63, 2.97), 2.78 times greater in the overweight than in those of normal weight ($P<0.001$. 95% CI: 1.94, 3.99) and 5.80 times greater in the obese than in the normal weight respondents ($P<0.001$. CI: 3.86, 8.69). Although, the odds ratios decreased for these variables as the number of underreporters identified increased, the same pattern was seen using approach 3. The odds of being an underreporter (approach 3) was 1.96 times greater in women than men ($P<0.001$. 95% CI: 1.51, 2.54), 2.72 times greater in the overweight ($P<0.001$. 95% CI: 2.01, 3.67) than in the normal weight respondents and 4.74 times greater in the obese compared to those of normal weight ($P<0.001$. 95% CI: 3.31, 6.79). This logistic regression analysis did not show an independent association between age and underreporting e.g. the odds of being an underreporter (using approach 3) in the middle aged group (36-50years) was 0.74 times that of the younger age group (18-35years) ($P=0.042$. 95% CI: 0.55, 0.99) while the odds ratio in the older age group (51-64years) was 0.91 that of those aged 18-35years ($P=0.583$. 95% CI: 0.65, 1.27).

In men and women, in each of the age groups, absolute energy and macronutrients intakes (fat, carbohydrate and protein) were significantly lower ($P<0.001$) in underreporters compared to others, irrespective of which approach was used to identify these underreporters (data not shown). When macronutrient intakes were expressed as a percentage of total energy intake, there was a pattern of a lower percentage energy from fat and higher percentages of energy from carbohydrate and protein in underreporters compared to valid energy reporters for all four approaches. The higher percentage energy from protein was consistently significantly different from valid energy reporters for men and women in each age group (e.g. men underreporters (approach 3) had 17.1% of total energy from protein compared to 15% in valid energy reporters ($P<0.001$) while women underreporters (approach 3) had 17% energy from protein compared to 14.9% in valid energy reporters ($P<0.001$). The lower percentage energy from fat was significantly different from valid energy reporters in women but not in men (e.g. men underreporters (approach 3) had 34.3% of total energy from fat compared to 35.2% in valid reporters (NS) while women underreporters had 34.1% of total energy from fat compared to 36.7% in valid energy reporters ($P<0.001$)). The higher percentage of total energy from carbohydrate was significantly different between underreporters and others in women but not in men (e.g. men underreporters (approach 3) had 44.1% of energy from carbohydrate compared to 43.4% in valid energy reporters while women underreporters (approach 3) had 46% energy from carbohydrate compared to 44.5% in valid energy reporters ($P<0.001$). It is of note that the differences in macronutrient intakes between underreporters and valid energy reporters in men and in women were consistent irrespective of the approach used to identify underreporters.

Tables 5.5 and 5.6 show the influence of excluding underreporters identified by approach 1 and approach 3 on energy and macronutrient intakes. Mean daily energy intakes increased by approximately 180 kcals/day in men and 165 kcals/day in women when underreporters, identified by approach 1, were excluded. Energy intakes increased by a further 80 kcals/day in men and 60 kcals/day in women when underreporters, identified by approach 3, were excluded. The influence of excluding increasing numbers of underreporters on macronutrient intakes (percent total energy) was less striking e.g. in men and women there was less than a 1% increase in the percentage of total energy from fat between the full sample and after excluding underreporters by approach 3. Similarly, there was less than a 1% decrease in the

percentage total energy from carbohydrate after excluding underreporters by approach 3, for both men and women.

The influence of excluding underreporters on the proportion of men and women attaining dietary targets for fat and carbohydrate was also addressed in Tables 5.5 and 5.6. The dietary target for fat of $\leq$ 35% of food energy was met by 31% of men. This fell to 29% when underreporters identified by approach 1 were excluded and to 28% when those identified by approach 3 were excluded (Table 5.5). While 34% of women met this target for fat, this fell to 28% and 26% of women after excluding approach 1-underreporters and approach 3-underreporters respectively. In 51-64year old women, where the prevalence of underreporting was highest at 39% (approach 3), the percentage of women meeting the dietary target for fat decreased from 46% to 37% after excluding underreporters identified by approach 3. The effect of excluding underreporters on the proportion of men and women meeting the dietary target for carbohydrate of $\geq$ 47% of food energy was less than that for fat, falling by one percentage point in men (23% to 22%) and by three percentage points in women (26% to 23%) after excluding underreporters (approach 3) (Tables 5.5 and 5.6).

Mean daily intakes of calcium (mg/day) and iron (mg/day) were significantly lower ($P<0.001$) in men and women underreporters compared to their counterparts who reported valid energy intakes, irrespective of which approach to the Goldberg equation (Goldberg *et al.*, 1991; Black, 2000b) had been used to identify them (data not shown). Although mean daily intakes of calcium and iron decreased when nutrient supplements were excluded, the significantly lower intakes in underreporters than in valid reporters remained (data not shown). Mean daily vitamin C intakes were, in general, lower in underreporters than others except in young men (18-35years) where underreporters had higher mean daily vitamin C intakes than valid energy reporters (data not shown). When vitamin C-containing supplements were excluded, however, underreporters, in each of the age groups, had significantly ($P<0.05$) lower intakes of vitamin C than valid energy reporters (data not shown). The opposite pattern was seen when micronutrient intakes were expressed per 10MJ of energy intake, where nutrient intakes (mg/10MJ) were, in general, higher in underreporters than in others due to the lower reported energy intakes in underreporters. These differences were significant in only some of the age groups but were consistent irrespective of the numbers of underreporters identified.

In general, absolute intakes of calcium and iron increased by about 6% in men and 6% to 9% in women when underreporters identified by approach 1 were excluded (Tables 5.5 and 5.6). This compares to an increase in calcium and iron intakes of 10% in both men and women when underreporters identified by approach 3 were excluded. Vitamin C intakes did not change remarkably in men after excluding underreporters (Table 5.5) while vitamin C intakes in women increased by 6% and 10% when underreporters, identified by approaches 1 and 3 respectively, were excluded (Table 5.6). As expected, the greatest differences in mean daily micronutrient intakes, after excluding underreporters, was seen in the groups with a high prevalence of underreporting e.g. in 51-64 year old women, mean daily iron intake increased from 14.3mg to 16.7mg/day, after excluding underreporters (approach 1) and to 17.7mg/day after excluding underreporters (approach 3) (Table 5.6).

The proportion of men and women with calcium, iron and vitamin C intakes below the average requirement (AR) (Scientific Committee for Food, 1993) for each nutrient is presented in Tables 5.5 and 5.6 for the full population and after excluding underreporters. In general, the proportion with intakes below the AR decreased when underreporters were excluded. As the proportion of men with calcium, iron and vitamin C intakes below the AR was lower than that in women, the effect of excluding underreporters on the adequacy of these nutrient intakes was much less marked in men than in women e.g. 23% of women had calcium intakes below the AR of 550mg compared to 10% of men and, after excluding underreporters (approach 3), 13% of women and 3% of men had calcium intakes below the AR. The prevalence of an inadequate iron intake was highest in menstruating women where the AR is 10mg/day. A total of 51% of 18-35 year old women and 46% of 36-50 year old women had iron intakes less than 10mg/day which decreased to 42% and 39% respectively after excluding underreporters (approach 1) and further decreased to 39% and 36% respectively after excluding underreporters by approach 3 (Table 5.6). Interestingly, the difference in the proportion of the population with intakes below the AR for calcium and vitamin C did not differ remarkably between excluding underreporters identified by approach 1 and the greater number identified by approach 3.

5.5 Discussion

Applying the Goldberg cut-offs according to approach 3 is an easy and practical way to identify a greater proportion of underreporters in the population than using the Goldberg

cut-off of 1.05 for EI/BMR_{est} alone. Approach 3 is dependent, however, on the validity of the use of the ePALs in classifying men and women into low, medium and high levels of activity. On a population level, the mean ePALs are remarkably similar to mean physical activity levels determined from energy expenditure measured by doubly labelled water (Black *et al.*, 1996). In each of the age groups of men and women, the mean ePALs and mean PALs are reasonably comparable also. Similarly, comparable values for ePAL and PAL were seen when the mean values were compared across BMI categories. This is a relevant finding as one of the recognised limitations of converting METS (expressed as MET hours) to energy expenditure (kcals) is that a resting metabolic rate (RMR) of 1kcal/kg body weight/hour is assumed (Ainsworth *et al.*, 1993). If the RMR is not equal to 1kcal/kg/hour then energy expenditure will be closely related to body weight e.g. in those with a high BMI. If a RMR of 1kcal/kg/hour had been assumed in this study, the mean ePAL would have been 1.77 in men and 1.76 in women. In addition, these ePALs would have been significantly correlated with body weight ($P< 0.010$) ($r^2 = 0.05$ in men, $r^2 = 0.28$ in women). Furthermore, ePAL, based on an assumed RMR of 1kcal/kg/hour, would have increased significantly with increasing BMI in both men and women. In this study, RMR was calculated as BMR multiplied by 1.1. While the mean and median RMR was 1.00, the range was from 0.65 to 1.38. The ePALs in this study are not significantly correlated with body weight in either men or women ($P> 0.05$) ($r^2 = 0.005$ in men, $r^2 = 0.002$ in women).

The mean ePALs in each activity category (approach 3) in men and women are lower than the FAO/WHO/UNU (1985) values. In men, the mean ePALs in the low, medium and high activity categories are 1.47, 1.77 and 2.22 respectively and in women, the mean ePALs are 1.47, 1.66 and 1.86 in the corresponding activity categories. When Black (2000a) used this approach of classifying respondents as low, medium and high activity according to the FAO/WHO/UNU (1985) physical activity levels, she also found that the mean PAL values in these categories in her study population were lower than the FAO/WHO/UNU (1985) values (1.49, 1.80 and 2.14 in low, medium and high activity categories in men and 1.43, 1.65 and 1.95 in low, medium and high activity categories in women (Black 2000a)). Indeed, the mean PALs from Black (2000a) are similar to the mean ePALs in these categories of activity in this study.

In theory, approach 4 could be expected to represent the best way to identify underreporters as it is a direct comparison of EI/BMR_{est} to a specific ePAL for that

respondent. Black (2000a) identified the 'true' underreporters in the population by identifying the lower 95% confidence limit of agreement between energy intake and energy expenditure and categorising energy intakes below this level as underreported. Energy expenditure in Black's paper was however, measured by doubly labelled water and as such is expected to be valid at the individual level. It is unlikely, however, that the ePALs in the present study are valid for all individuals. The ePALs in the present study ranged from 1.10 to 4.04. Black *et al.*, (1996) proposed that the 'boundaries' of energy expenditure are described by PALs in the range of 1.2 to 2.5 where 1.2 represents an extremely sedentary lifestyle and 2.5 represents a sustainable active lifestyle. In the present study, the vast majority (96%) of ePALs were within this range but there were, nonetheless, 8/1331 respondents with an ePAL below 1.2 and 45/1331 respondents with an ePAL greater than 2.5. As the physical activity questionnaire was a measure of activity over the previous year, the values outside the range of 1.2 to 2.5 cannot be considered as valid at an individual level. However, classifying these respondents as either low or high activity (as in approach 3) may be a valid classification. It is likely that a low ePAL represents low activity, although the actual value may not be considered valid at an individual level. Similarly, high ePALs, beyond the acceptable boundary of 2.5, are likely to represent high activity. It is possible that physical activity was over reported by some respondents. Although total METS were adjusted to represent 24 hours, there were respondents who reported high levels of activity at work over long periods of time. Overreporting of physical activity has been shown by Lichtman *et al.*, (1992) in obese subjects and the possibilty of overreporting physical activity has been suggested by many authors (Körtzinger *et al.*, 1992, Heerstrass *et al.*, 1998, Briefel *et al.*, 1997, Gnardellis *et al.*, 1998, Heitmann *et al.*, 2000, Goris *et al.*, 2001, Ball *et al.*, 2001). In summary, approach 4 is not as useful as approach 3 in identifying underreporters because ePAL is unlikely to be consistently valid for each individual. For this reason, the effect of identifying an increased number of underreporters on the characteristics associated with underreporting and on nutrient intakes was determined by comparing approach 1 and approach 3. As approaches 2 and 3 were very similar, approach 2 could equally have been chosen for comparison with approach 1.

Three of the most frequently cited characteristics of underreporters relate to sex, BMI and age where the highest numbers of underreporters are women, those who are overweight or obese or older people (Macdiarmid & Blundell, 1998). These findings

have not been consistently reported, however, with evidence of underreporting in almost all subgroups of the population (Macdiarmid & Blundell, 1998). It has been suggested that the lack of agreement between authors on the characteristics of underreporters is related to the fact that many studies have characterised only a subgroup of underreporters in using the Goldberg cut-off based on a PAL of 1.55 (Black 2000a). In this study, the independent associations between sex, BMI and underreporting held true when 19% of the population were identified as underreporters (approach 1) and when 30% of the population of the population were identified as underreporters (approach 3). Although only three characteristics were examined, this study clearly shows that, irrespective of the number of underreporters identified, women and those who are overweight or obese are significantly more likely to report invalid energy intakes than men or those who are normal weight. Unlike other studies (Hirvonen *et al.*, 1997; Briefel *et al.*, 1997; Lafay *et al.*, 1997; Gnardellis *et al.*, 1998; Braam *et al.*, 1998) age was not independently associated with underreporting. It is possible that the relationship between age and underreporting is through BMI as the highest prevalence of overweight and obesity is seen in the older age group in this population (McCarthy *et al.*, 2001)

The pattern in this study of a higher percentage total energy from protein, a higher percentage total energy from carbohydrate and a lower percentage total energy from fat in underreporters compared to others has been widely reported by other authors (Körtzinger *et al.*, 1997; Pryer *et al.*, 1997; Price *et al.*, 1997; Briefel *et al.*, 1997; Johansson *et al.*, 1998; Becker at al., 1999; Lafay *et al.*, 1997) but the differences have not however, been consistently significant. The greatest agreement between studies is in the higher percentage energy from protein in underreporters (Heitmann & Lissner, 1995; Heitmann *et al.*, 2000) suggesting either good reporting or overreporting of protein intake. Poorer agreement exists between studies on whether carbohydrate and fat intakes are underreported disproportionately. Poppitt *et al.*, (1998) in covert measurements of food intake over 24 hours in 30 women, found that the reported intakes of added sugar were significantly lower than observed, with no significant differences between reported and observed fat and protein intakes. On the other hand, Goris *et al.*, (2000) found that the reported percentage energy from fat was significantly related to underreporting of energy intake in 30 obese men while the percentage energy from carbohydrate and protein were not significantly related to underreporting in this group. It is however, difficult to validate reported fat and carbohydrate intakes, as there

are no biomarkers for these nutrients, unlike protein, where urinary nitrogen is used as a biomarker of intake (Heitmann & Lissner, 1995). In addition, carbohydrate and fat intakes, expressed as a percentage of energy intake, are interrelated making it difficult to distinguish if different fat and carbohydrate intakes (% energy) in underreporters are directly due to a misreported intake of one or the other nutrient.

The lower micronutrient intakes and higher micronutrient densities in underreporters in this study have been reported by others with reasonable consistency (Lührmann *et al.*, 2001; Pryer *et al.*, 1997; Briefel *et al.*, 1997; Hirvonen *et al.*, 1997). Price *et al.* (1997) specifically reported on calcium, iron and vitamin C intakes only and found significantly lower absolute intakes (mg/day) and higher energy adjusted intakes (mg/MJ) in low energy reporters with an EI/BMR_{est} less than 1.1. In this study, the proportion of men and women with micronutrient intakes below the AR decreased as more underreporters were identified, with the greatest differences relating to iron intakes in menstruating women. Rothenberg *et al.*, (1998) reported similar findings where the mean proportion of individuals with intakes below two-thirds of the recommended daily allowance for protein and five micronutrients decreased as EI/BMR increased. Similarly, Haraldsdóttir *et al.*, (1998) reported that the percentage of individuals with vitamin and minerals intakes below recommended intakes decreased by 1 to 14 percentage points when underreporters were excluded. Clearly, identifying energy underreporters is necessary for the interpretation of the adequacy of micronutrient intakes, and in particular, iron intakes in women.

Studies that have presented nutrient intakes after excluding underreporters (Price *et al.*, 1997; Billson *et al.*, 1999, Gnardellis *et al.*, 1998; Hirvonen *et al.*, 1998; Brunner *et al.*, 2001; Macdiarmid *et al.*, 1996), or who have compared nutrient intakes between underreporters and valid reporters (Pryer *et al.*, 1997; Lührmann *et al.*, 2001; Briefel *et al.*, 1997; Johansson *et al.*, 1998) have used one cut-off for EI/BMR to identify underreporters. The cut-offs used have ranged from 0.9 to 1.35. In this study it was possible to address the impact of excluding underreporters identified by a series of cut-offs, according to category of physical activity, compared to the use of a single cut-off for EI/BMR_{est} conservatively calculated by assuming a low physical activity level in the population. Excluding underreporters identified by approach 1, resulted in an increased mean energy and nutrient intakes in men and women. These mean intakes (energy, nutrients, nutrient densities) did not change remarkably after excluding the greater

number of underreporters identified by approach 3. This is likely, due to the fact that underreporters identified by approach 1 represent the lower range of energy intakes and hence the lower range of intakes for most nutrients. The additional underreporters identified by approach 3 are likely to represent a wider range of both energy and nutrient intakes. In men, mean daily energy intake was 1615 kcals/day in approach 1-underreporters compared to 1894 kcals/day in approach 3-underreporters. The corresponding energy intake in women was 1292 kcals/day for approach 1-underreporters and 1385 kcals/day for approach 3-underreporters.

In agreement with other authors (Hirvonen *et al.*, 1997; Gnardellis *et al.*, 1998), there was little nutritional significance to the small increase in the percentage energy from fat in this study, after underreporters were excluded. In contrast, excluding underreporters clearly decreased the proportion of the population, especially women, meeting recommended fat intakes. This decrease was greatest in older women who had the lowest mean percentage energy from fat while having the highest prevalence of underreporting at 39% and the highest prevalence of obesity at 30% (McCarthy *et al.*, 2001). In addition, the decrease in the proportion of the population meeting recommended fat intakes continued as more underreporters were identified and subsequently excluded. This highlights the need to identify all respondents with invalid energy intakes to correctly interpret fat intakes.

These results show that the trends in nutrient intakes between underreporters and valid reporters and the influence of excluding underreporters on nutrient intakes, reported in the literature are likely to hold true if approach 3 had been adopted in these studies as a means of improving the identification of underreporters. This work also shows, however, that, in subgroups of the population where underreporting is prevalent, being better able to identify underreporters will have a considerable influence on the interpretation of nutrient adequacy in that group.

Table 5.1 Mean (SD), median and percentiles of estimated physical activity level (ePAL) for men and women in the NSIFCS.

		Men	Women
		(n = 637)	*(n = 694)*
		ePAL	ePAL
Mean		1.81	1.69
(SD)		(0.42)	(0.27)
Median		1.71	1.66
	Percentiles 10	1.36	1.39
	20	1.46	1.48
	30	1.56	1.54
	40	1.64	1.60
	50	1.71	1.66
	60	1.81	1.72
	70	1.95	1.78
	80	2.12	1.86
	90	2.37	2.03

Table 5.2 A comparison of Physical Activity Levels (PAL) from doubly labelled water measurements of energy expenditure (Black *et al.*, 1996) and estimated Physical Activity Levels (ePAL) measured by questionnaire in the present North/South Ireland Food Consumption Survey (NSIFCS) for men and women aged 18-64 years.

		Physical Activity Levels			Estimated Physical Activity Levels				
		Black *et al.*, 1996 (PAL = TEE/BMR)			NSIFCS (ePAL = TEE/BMR)				
Sex	Age Groups	*n*	Mean	(SD)	*n*	Mean	(SD)		
Men	18-64 years	107	1.77		637	1.81	(0.42)		***
	18-29 years	56	1.85	(0.33)	156	1.88	(0.46)	a	***
	30-39 years	36	1.77	(0.31)	150	1.88	(0.41)	a	***
	40-64 years	15	1.64	(0.17)	331	1.74	(0.40)	b	*
Women	18-64 years	212	1.69		694	1.69	(0.27)		
	18-29 years	89	1.70	(0.28)	158	1.67	(0.29)	ns	
	30-39 years	76	1.68	(0.25)	190	1.73	(0.26)		
	40-64 years	47	1.69	(0.23)	346	1.68	(0.27)		

Significant differences in ePAL between men and women in same age groups (t-test): *** $P<0.001$, * $P<0.05$.

[ab] Significant differences in ePAL between age groups in each sex. $P<0.05$ (ANOVA), [ns] = non significant.

Table 5.3 A comparison of Physical Activity Levels (PAL) from doubly labelled water measurements of energy expenditure (Prentice *et al.*, 1996) and estimated Physical Activity Levels (ePAL) measured by questionnaire in the present North/South Ireland Food Consumption Survey (NSIFCS) according to body mass index.

		Physical Activity Levels			Estimated Physical Activity Levels				
		Prentice *et al.*, 1996 (PAL = TEE/BMR)			NSIFCS† (ePAL = TEE/BMR)				
Sex	BMI Groups	*n*	Mean	(SD)	*n*	Mean	(SD)		
Men 18-64 years	BMI < 24.9	72	1.80	(0.32)	198	1.82	(0.39)	ns	***
	BMI = 25-29.9	23	1.86	(0.29)	280	1.81	(0.41)		***
	BMI = 30-34.9	4	1.82	(0.29)	97	1.74	(0.42)		
	BMI > 35	8	1.52	(0.23)	23	1.79	(0.57)		
Women 18-64 years	BMI < 24.9	126	1.67	(0.27)	349	1.70	(0.27)	ns	
	BMI = 25-29.9	45	1.73	(0.25)	222	1.66	(0.23)		
	BMI = 30-34.9	29	1.73	(0.23)	73	1.73	(0.30)		
	BMI > 35	12	1.65	(0.20)	35	1.70	(0.39)		

† n = 1277 respondents with BMI and ePAL measurements.

Significant differences in ePAL between men and women in same BMI categories (t-test): *** $P<0.001$.

ns No significant differences in ePAL between BMI categories in each sex. $P> 0.05$ (ANOVA).

Table 5.4 The number (n) and percentage (%) of underreporters identified by each of the four approaches according to sex and age group.

			Approach 1		Approach 2		Approach 3		Approach 4	
		n	n (%)		n (%)		n (%)		n (%)	
All	18-64 years	1331	259 (19%)		399 (30%)		393 (29.5%)		420 (31.5%)	
Men	18-64 years	637	96 (15%) [a]		171 (27%) [a]		162 (25%) [a]		178 (28%) [a]	
	18-35 years	243	30 (12%) [a]		61 (25%) [a]		58 (24%) [a]		70 (29%) [a]	
	36-50 years	233	36 (15%) [a]		63 (27%) [a]		58 (25%) [a]		65 (28%) [a]	
	51-64 years	161	30 (19%) [a]		47 (29%) [a]		46 (29%) [a]		43 (27%) [a]	
Women	18-64 years	694	163 (23%) [a]	***	228 (33%) [a]	*	231 (33%) [a]	**	242 (35%) [a]	**
	18-35 years	262	60 (23%) [a]	**	87 (33%) [a]	*	88 (33.5%) [a]	*	90 (34%) [a]	ns
	36-50 years	274	56 (20%) [a]	ns	80 (29%) [a]	ns	81 (29.5%) [a]	ns	90 (33%) [a]	ns
	51-64 years	158	47 (30%) [a]	*	61 (39%) [a]	ns	62 (39%) [a]	*	62 (39%) [a]	*

Approach 1: Cut-off for EI/BMR = 1.05 as defined by Black *et al.*, (2000).

Approach 2: Sample divided into tertiles of METS and cut-offs based on FAO/WHO/UNU 1985 PALs for low medium and high activities.

Approach 3: Sample divided into low medium and high activity based on FAO/WHO/UNU 1985 PALs. Cut-offs applied as approach 2.

Approach 4: Individual cut-offs using subject specific ePAL.

Significant differences in number of underreporters, identified by the same approach, between men and women (Chi-Square test):

*** $P<0.001$, ** $P<0.01$, * $P<0.05$, ns = non significant

[a] No significant differences in number of underreporters identified between age groups in each sex. $P>0.05$ (Chi-Square).

Table 5.5 Energy, macronutrient and micronutrient intakes in men according to age group including underreporters (all) and excluding underreporters (UR) as identified by approaches 1 and 3.

		All ages			18-35years			36-50years			51-64years		
		All	Excluding UR		All	Excluding UR		All	Excluding UR		All	Excluding UR	
			Approach 1	Approach 3		Approach 1	Approach 3		Approach 1	Approach 3		Approach 1	Approach 3
		n = 637	*n = 541*	*n = 475*	*n = 243*	*n = 213*	*n = 185*	*n = 233*	*n = 197*	*n = 175*	*n = 161*	*n = 131*	*n = 115*
Energy (MJ)	Mean	11.0	11.8	12.1	11.7	12.3	12.7	11.0	11.8	12.2	10.2	10.9	11.2
	(SD)	(3.1)	(2.6)	(2.6)	(3.1)	(2.7)	(2.7)	(3.0)	(2.4)	(2.4)	(2.8)	(2.5)	(2.5)
% Total energy from:													
Fat (%)	Mean	35.0	35.2	35.2	35.2	35.2	35.0	35.6	35.8	35.6	33.8	34.4	34.5
	(SD)	(5.7)	(5.4)	(5.4)	(5.4)	(5.3)	(5.0)	(5.8)	(5.4)	(5.4)	(5.8)	(5.5)	(5.5)
Carbohydrate (%)	Mean	43.6	43.4	43.4	42.7	42.4	42.0	43.2	43.0	43.1	45.3	45.6	45.6
	(SD)	(6.4)	(6.5)	(6.6)	(6.1)	(6.2)	(6.0)	(6.3)	(6.2)	(6.4)	(6.6)	(6.8)	(6.9)
Protein (%)	Mean	15.5	15.1	15.0	14.8	14.5	14.0	15.9	15.5	15.4	16.2	15.7	15.5
	(SD)	(2.7)	(2.4)	(2.4)	(2.6)	(2.4)	(2.0)	(2.6)	(2.2)	(2.2)	(2.6)	(2.5)	(2.4)
Alcohol (%)	Mean	5.8	6.1	6.3	7.2	7.6	7.9	5.2	5.6	5.7	4.7	4.4	4.4
	(SD)	(6.9)	(7.0)	(7.1)	(7.7)	(7.7)	(7.7)	(6.2)	(6.4)	(6.6)	(6.2)	(6.0)	(6.2)
Target of ≤35% food energy from fat													
% achieving target		31%	29%	28%	24%	22%	20%	28%	27%	28%	46%	42%	40%
Target of ≥47% food energy from carbohydrate													
% achieving target		23%	22%	22%	21%	20%	20%	18%	17%	18%	32%	31%	30%
Calcium (mg)	Mean	954	1015	1046	1005	1055	1093	970	1037	1072	855	916	933
	(SD)	(355)	(338)	(337)	(372)	(354)	(342)	(364)	(347)	(346)	(292)	(278)	286
Iron (mg)	Mean	14.5	15.4	15.7	14.4	15.2	15.5	14.9	15.7	15.9	14.2	15.1	15.5
	(SD)	(5.6)	(5.5)	(5.4)	(5.9)	(5.8)	(5.8)	(5.6)	(5.2)	(4.9)	(5.2)	(5.3)	5.4
Vitamin C (mg)	Mean	118	115	117	129	114	113	118	128	130	100	100	101
	(SD)	(227)	(158)	(164)	(304)	(146)	(148)	(188)	(201)	(211)	(114)	(86)	91
% of population with intakes below the average requirement (AR)^													
Calcium (AR = 550mg)		10%	5%	3%	10%	5%	2%	10%	4%	3%	12%	5%	5%
Iron (AR = 7mg)		2%	<1%	<1%	3%	1%	<1%	2%	0%	0%	<1%	0%	0%
Vitamin C (AR = 30mg)		7%	5%	5%	10%	8%	8%	6%	3%	3%	6%	3%	3%

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Table 5.6 Energy, macronutrient and micronutrient intakes in women according to age group including underreporters (all) and excluding underreporters (UR) as identified by approaches 1 and 3.

		All ages			18-35years			36-50years			51-64years		
		All	Excluding UR		All	Excluding UR		All	Excluding UR		All	Excluding UR	
			Approach 1	Approach 3		Approach 1	Approach 3		Approach 1	Approach 3		Approach 1	Approach 3
		n = 694	*n = 531*	*n = 463*	*n = 262*	*n = 202*	*n = 174*	*n = 274*	*n = 218*	*n = 193*	*n = 158*	*n = 111*	*n = 96*
Energy (MJ)	Mean	7.7	8.4	8.6	7.7	8.4	8.6	7.8	8.4	8.7	7.3	8.2	8.4
	(SD)	2.1	1.7	1.7	1.9	1.7	1.6	2.0	1.8	1.8	2.0	1.5	1.5
% Total energy from:													
Fat (%)	Mean	35.9	36.5	36.7	36.2	36.6	36.7	36.1	36.9	33.8	34.9	35.6	36.1
	(SD)	(5.6)	(5.3)	(5.3)	(5.3)	(4.9)	(5.0)	(5.6)	(5.3)	(5.7)	(6.2)	(5.7)	(5.8)
Carbohydrate (%)	Mean	45.0	44.6	44.5	44.3	44.2	44.2	44.6	44.1	46.0	46.9	46.5	46.1
	(SD)	(6.1)	(6.1)	(6.1)	(5.7)	(5.8)	(5.8)	(6.0)	(6.1)	(5.9)	(6.3)	(6.2)	(6.4)
Protein (%)	Mean	15.6	15.1	14.9	14.7	14.2	14.1	15.8	15.3	17.4	16.7	16.1	15.9
	(SD)	(2.8)	(2.6)	(2.6)	(3.0)	(2.8)	(2.8)	(2.5)	(2.2)	(2.5)	(2.8)	(2.5)	(2.5)
Alcohol (%)	Mean	3.5	3.7	3.8	4.9	5.0	5.0	3.3	3.6	3.6	1.5	1.8	1.8
	(SD)	(4.6)	(4.7)	(4.8)	(5.4)	(5.5)	(5.6)	(4.2)	(4.3)	(4.3)	(2.9)	(3.0)	(3.1)
Target of ≤35% food energy from fat													
% achieving target		34%	28%	26%	24%	22%	21%	32%	26%	24%	46%	43%	37%
Target of ≥ 47% food energy from carbohydrate													
% achieving target		26%	24%	23%	24%	23%	23%	24%	21%	20%	33%	31%	29%
Calcium (mg)	Mean	747	805	824	719	776	799	768	810	822	757	847	872
	(SD)	(304)	(302)	(311)	(313)	(318)	(331)	(296)	(286)	(296)	(302)	(298)	(301)
Iron (mg)	Mean	14.3	15.6	15.7	14.4	15.6	15.2	14.2	15.1	15.2	14.3	16.7	17.7
	(SD)	(19.0)	(20.3)	(20.4)	(19.6)	(20.9)	(20.0)	(16.8)	(16.8)	(16.8)	(21.4)	(25.1)	(26.8)
Vitamin C (mg)	Mean	109	115	119	99	101	106	114	119	120	117	134	141
	(SD)	(186)	(199)	(210)	(193)	(205)	(219)	(191)	(198)	(205)	(166)	(189)	(201)
% of population with intakes below the average requirement (AR)^													
Calcium (AR = 550mg)		23%	14%	13%	26%	16%	17%	19%	13%	13%	23%	14%	11%
Iron		39%	32%	30%	51%	42%	39%	46%	39%	36%	8%	1%	1%
(AR = 10mg menstruating women)													
(AR = 6mg post menopause)													
Vitamin C (AR = 30mg)		9%	6%	6%	9%	8%	7%	8%	5%	5%	9%	5%	5%

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Chapter 6

Changes in Body Weight and Energy Underreporting in the North/South Ireland Food Consumption Survey

6.1 Introduction

Many food intake studies have reported energy intakes that are significantly lower than either measured or estimated energy requirements (Black *et al.*, 1991; Hill & Davies, 2001). Consequently, the validity of energy intakes against energy needs must be assessed and presented for all food intake studies. Energy requirements can be directly measured in the free-living situation from total energy expenditure (TEE) using doubly labelled water (DLW). This method is usually used in smaller studies however, as it is time consuming, expensive and requires additional expertise and resources to food intake data collection. The Goldberg equation (Goldberg *et al.*, 1991; Black, 2000) is a useful and practical means of comparing energy intakes, on either a group or individual basis, to estimated requirements. It compares energy intakes, expressed as energy intake/basal metabolic rate (EI/BMR), to a physical activity level (PAL), which is a multiple of BMR, and subsequently calculates a 'cut-off' for EI/BMR, below which energy intakes are not considered valid. The equation takes into account the within subject variation in measuring energy intake and basal metabolic rate, the between subject variation in PAL as well as the sample size and the time covered by the food record (Goldberg *et al.*, 1991; Black, 2000)

One of the conditions of truly comparing energy intake (EI) to energy expenditure (EE) is that energy balance within the population is measured. This applies irrespective of whether doubly labelled water or the Goldberg equation is used to compare energy intakes and expenditure/requirements. Weight is gained if EI is greater than EE and weight is lost if EI is less than EE. While most food intake studies address the validity of their energy intakes, a minority report repeat measurements of body weight, before and after a period during which food intakes are recorded, to assess energy balance.

Studies that measured changes in body weight report in general, a tendency towards weight loss when food intakes are being recorded. Of 14 studies reviewed that measured body weight before and after food intake recording in adults, all reported a mean weight loss within the range of -0.1kg to -1.0kg per week (Pannemans & Westerterp, 1993; deVries *et al.*, 1994; Raben *et al.*, 1995; Lissner *et al.*, 1989; Milne *et al.*, 1991; Lindroos *et al.*, 1993; Kempen *et al.*, 1995; Sawaya *et al.*, 1996; Martin *et al.*, 1996; Taren *et al.*, 1999; Goris *et al.*, 2001a; 2001b; Goris *et al.*, 2000; Goris & Westerterp, 1999). Most reported a mean loss of -0.15kg to -0.4kg over a week. Earlier evidence of weight changes during food intake recording came from dietary

intervention studies that required weight maintenance. Those studies that based energy requirements for the intervention on previously reported energy intakes, found that a significantly higher energy intake was required to maintain weight (deVries *et al.*, 1994; Mertz *et al.*, 1991). .

There are many valid reasons for weight loss during food intake recording e.g. dieting to lose weight, an unusually lower food intake due to illness or, to a lesser extent, a higher energy requirement during that period. Weight loss outside of this is most likely linked to energy underreporting and the term 'undereating' is used to describe the reduced food intake associated with underreported energy intakes (Black *et al.*, 1995). Some investigators have quantified the extent to which undereating contributes to energy underreporting by adjusting energy intakes by the energy value of the weight lost. Goris and colleagues showed that undereating accounted for all underreported energy intake in a study of food intakes in dietitians (Goris & Westerterp, 1999) and for 70% of energy underreporting in obese men (Goris *et al.*, 2000). In two other similar studies, there was no undereating and the difference between energy intake and expenditure was due to underrecording exclusively (Goris *et al.*, 2001a: 2001b).

Body weight was measured in the North/South Ireland Food Consumption Survey (NSIFCS), before and after the food diary record, as part of assessing the validity of reported energy intakes in the survey. The objective of this chapter is (i) to examine weight changes in the NSIFCS population over the 7 days when the food diary was kept, (ii) to examine the relationship between energy intake and these weight changes and, (iii) to measure the impact of adjusting energy intakes for weight lost or gained on the validity of energy intakes using the Goldberg equation.

6.2 Methods

6.2.1 The North/South Ireland Food Consumption Survey

The North/South Ireland Food Consumption Survey, carried out between 1997 and 1999, generated a database of food and nutrient intakes, health and lifestyle information and anthropometric measurements on a random selection of 1379 adults from the Republic of Ireland and Northern Ireland. The survey design and sampling procedures have been described in detail by Kiely *et al.*, (2001).

6.2.2 Food and Energy Intakes

Food intakes were collected using a 7 day food diary. The protocol followed has been detailed by Harrington *et al.*, (2001). Respondents recorded every item eaten or drank during 7 days in a specially designed food diary. The amount of each item was also recorded as was the brand name and method of cooking if relevant. The ingredients used in composite dishes were also recorded. Respondents were visited by the same fieldworker, up to four times during the food diary week, to quantify foods recorded in the diary and to ensure that the diary was complete. A variety of methods was used to quantify the foods and drinks recorded in the following order: weighed replicate portions of foods or drinks recorded, a photographic food atlas, manufacturer's data and household measurements. Respondents were encouraged to continue their normal eating pattern during the survey. Food and drinks were analysed for energy and nutrients using WISP © (Weighed Intake Software Program. Tinuviel Software, Warrington, U.K.). This nutrient analysis program is based on McCance and Widdowson's 'The Composition of Foods' (Holland *et al.*, 1995) and published supplements (Holland *et al.*, 1988; Holland *et al.*, 1989; Holland *et al.*, 1991; Holland *et al.*, 1992; Holland *et al.*, 1993; Chan *et al.*, 1994; Chan *et al.*, 1995; Chan *et al.*, 1996; Holland *et al.*, 1996). The nutrient composition database was expanded to include 860 additional foods, drinks or dishes eaten by the respondents in this survey.

6.2.3 Body Weight

Body weight was measured in duplicate at both the beginning of the food diary week and after the food diary record was completed. Weight was measured to the nearest 0.1kg, using a Seca Alpha 770 digital personal weighing scales (CMS Weighing Ltd., London, UK), with the subject wearing light clothing, after voiding and after removing any keys or coins from their pockets (McCarthy *et al.*, 2001).

The number of days between the body weight measurements was recorded for each respondent. In this study, respondents in whom the measurements were taken 6 to 11 days apart were included. In addition, only respondents who were considered weight stable were included in the analysis for this chapter. In other words, respondents who reported dieting to lose weight, trying to gain weight or a reduced food intake due to being unwell during the week of the survey were excluded. Respondents were subsequently classified according to the difference in their body weight over the food diary week. 'Weight loss' was defined as a decrease in body weight of 0.1kg or more,

'weight gain' as an increase in body weight of 0.1kg or more and 'no weight change' as a difference in body weight of less than 0.1kg. Weight differences, over the food diary week, were calculated and respondents were subsequently divided into quintiles of weight change for men and women separately. Differences in both mean daily energy intakes and in energy intake on each of the survey days were examined between the quintiles of weight change.

6.2.4 Estimated Physical Activity Levels and Identifying Energy Underreporters

Basal Metabolic Rate (BMR) was estimated using the Schofield equations (Schofield *et al.*, 1985) in 18 to 59 year olds and using the equations from the 1991 U.K. 'Dietary Reference Values' (Department of Health, U.K., 1991) for those aged 60-64 years. The Goldberg equation (Goldberg *et al.*, 1991), which calculates a cut-off for energy intake divided by basal metabolic rate (EI/BMR), below which energy intakes are not considered valid, was used to identify energy underreporters. This equation has been described in detail by Goldberg *et al.*, (1991) and Black (2000) and basically calculates the lower 95% confidence limit of agreement between energy intake (expressed as EI/BMR) to energy expenditure (expressed as physical activity level (PAL)).

In this survey, a physical activity questionnaire was used to calculate an estimated physical activity level (ePAL) for each respondent, which allowed respondents to be subsequently classified as low, moderate or high activity according to the FAO/WHO/UNU (1985) PALs that define these categories. The questionnaire was developed by the Institute of Public Health, University of Cambridge, U.K. (Wareham *et al.*, 2002) and asked respondents about their usual activity at home, work and recreation over the previous year. The questionnaire data were analysed by the Institute of Public Health and presented as total METS for home, work and recreation. A MET score is the energy cost of an activity, expressed as a multiple of resting metabolic rate, where one MET is the equivalent of the energy expended while sitting which is approximately 3.5mls of oxygen per kilogram body weight per minutes (Ainsworth *et al.*, 1993). The time spent at an activity, as recorded in the questionnaire, was multiplied by the MET score for that activity (James and Schofield, 1990; Ainsworth *et al.*, 1993) and the totalled METS reflected both time and intensity of activity at home, work and recreation.

As the questionnaire was not designed to calculate a physical activity level for each respondent, the present author further examined the data before calculating an estimated PAL for respondents. This has been detailed in chapter 4 and, in summary, involved examining the apparent validity and accuracy of all of the answers in the questionnaire, determining the extent to which the questionnaire accounted for the 24 hour day and examining if all activities were included in total METS. The outcome was that 17 respondents were excluded and changes were made to either the time spent at an activity or the METS for an activity in 229 respondents. In addition, activities not included in total METS (e.g. time asleep, time watching TV, time travelling by car) were included. In respondents where the total time was less than 24 hours, the remaining time was taken as sedentary and, in respondents with a total time above 24 hours, total METS was adjusted proportionately across all activities to represent 24 hours. The adjusted total METS was multiplied by resting metabolic rate (taken as BMR multiplied by 10% and expressed as kcals/hour) to calculate energy expenditure (kcals) (Ainsworth *et al.*, 1993). Energy expenditure was subsequently divided by BMR to calculate an estimated PAL (ePAL) for each respondent. Men and women were subsequently categorised as low, moderate or high activity. In men low activity was defined as an ePAL < 1.665, moderate activity as an ePAL of 1.665 to 1.94 and high activity as an ePAL > 1.94. In women, low activity was defined as an ePAL < 1.60, moderate activity as an ePAL of 1.60 to 1.715 and high activity as an ePAL > 1.715. The mid-points of the above categories are the FAO/WHO/UNU (1985) physical activity levels for low, moderate and high activity in men and women (Men: 1.58, 1.78, 2.10 respectively. Women: 1.56, 1.64, 1.82 respectively). These FAO/ WHO/ UNU (1985) PALs were used in the Goldberg equation to identify underreporters. The cut-offs calculated were 1.05 (low activity men), 1.06 (low activity women), 1.21 (moderate activity men), 1.11 (moderate activity women), 1.42 (high activity men) and 1.23 (high activity women). Underreporters were those whose EI/BMR_{est} was below the relevant cut-off.

6.2.5 Adjustment of Energy Intakes

Energy intakes were adjusted in three cumulative stages. After each adjustment the revised energy intake was used to recalculate EI/BMR_{est} and an amended prevalence of underreporting. In the first place, energy intake was increased in those who lost weight using the assumption that 1kg of body weight provides 30MJ (7140kcal) (Westerterp *et al.*, 1995). This weight loss was taken to represent 'undereating' in a sample that was

expected to be weight stable. Secondly, energy intake in energy underreporters was increased according to weight gained, again based on the assumption that 1kg of body weight provides 30MJ (Westerterp *et al.*, 1995). This weight gain was taken as food intake not recorded in energy underreporters. Thirdly, energy intakes were increased in underreporters (as identified after the two previous adjustments) to eliminate underreporting i.e. energy intakes were increased so that the corresponding EI/BMR_{est} was above the relevant cut-off for energy underreporting. The effect of these three cumulative adjustments on energy intake, EI/BMR_{est} and on the prevalence of underreporting in men and women was examined. The contribution of reported energy intake to the total adjusted energy intake was calculated, as was the contribution of the three levels of energy intake adjustment described above. These results are presented for men and women in low, moderate and high activity categories.

6.2.6 Statistical analysis

Statistical analysis was performed using SPSS ® (version 10.0, SPSS Inc., Chicago, IL). Independent t-tests were used to compare the mean weight difference over the survey week between men and women in each age category and between men and women underreporters. A one-way analysis of variance (ANOVA) was used to test for differences in the mean weight difference between age groups within men and women. Similarly, one-way analyses of variance were used to examine the differences in mean weight change, mean energy intakes, mean EI/BMR_{est} and mean ePAL across quintiles of weight change in men and women. The Scheffe post hoc test was used when groups had equal variances and the Tamhane post hoc test was used when groups had unequal variances (Coakes & Steed, 1999). Chi-squared analysis was used to test for differences in the proportion of underreporters between quintiles of weight change. When mean energy intakes on each survey day were examined across quintiles of weight change, both one-way and two-way analysis of variance were carried out to examine the effect of survey day and quintiles of weight change, and the interaction of both, on energy intakes in both men and women. Significance was defined as $P<0.05$ for all analyses.

6.3 Results

A total of 994 (72%) of the 1379 respondents in the NSIFCS had a body weight measurement taken before and after the food diary, within a timeframe of 6 to 11 days (Figure 6.1). Of the 994, 490 lost 0.1kg of weight or more. A total of 70 of these

respondents were excluded on the basis that they were intentionally trying to lose weight (n = 65) or that they reported a reduced food intake during the food diary week because of illness (Figure 6.1). In contrast, only 3/419 respondents who gained $\geq$ 0.1kg were excluded as they reported that they were intentionally trying to gain weight (Figure 6.1). The remaining 85 respondents showed minimal weight changes of <0.1kg over the week thus leaving a sample of 921 respondents for further analysis (Figure 6.1).

The mean weight difference among these 921 respondents was a loss of 0.05kg (Table 6.1). Although the actual values are small, the mean weight difference in men and women in each age group was a weight loss (Table 6.1). There was no difference in the mean weight change over the week between men or women or between any of the age groups (Table 6.1). Indeed, there was no difference in mean weight change between energy underreporters and others also (-0.10kg *vs.* -0.04kg. $P>0.05$). In addition, the proportion of the sample that lost weight, gained weight or showed no weight change was very similar between men and women in each age group and among underreporters also (Table 6.1).

Table 6.2 presents the quintiles of weight difference calculated separately for men and women. Broadly speaking, those in quintile 1 lost approximately 1kg, those in quintile 2 lost 0.5kg, those in quintile 3 showed little weight change, those in quintile 4 gained less than 0.5kg and those in quintile 5 gained up to 1kg. The range of weight change was greater in men than in women with a significantly higher mean weight loss among men in quintiles 1 and 2 ($P<0.001$) than women in the corresponding quintiles. This was also seen in quintile 5 where the mean weight gain was higher in men than in women ($P=0.007$) (Table 6.2). There were no differences in mean energy intakes between the quintiles for either men or women ($P>0.05$). This was also the case when EI/BMR_{est} was examined across quintiles. Habitual energy expenditure, as represented by ePAL, didn't vary significantly between quintiles either. While the highest prevalence of underreporting in men was seen in quintile 1 (32%), it was not significantly different than in the other quintiles (20-23%). In women, the prevalence of underreporting was lowest (21%) in the quintile that gained the most weight (quintile 5) but this was also not significantly different than in the other quintiles (30-36%). Of note is the fact that underreporters were present in all quintiles irrespective of weight gain or loss (Table 6.2).

Energy intakes on each of the 7 survey days are examined across the quintiles of weight change in Figures 6.2 and 6.3 for men and women respectively. For all men and all women, energy intakes did not differ significantly between the survey days (data not shown). In men, there was no significant interaction between quintile of weight change and survey day on energy intakes (Figure 2) (two-way ANOVA. $P>0.05$). One-way analysis of variance did show that men who lost the most weight (quintile 1) had lower energy intakes from day 4 onwards than earlier in the week ($P=0.03$). There was no significant change in energy intakes on any of the survey days among men in the other quintiles. There was also no difference in energy intakes on any given survey day between men in the 5 quintiles of weight change. In women, a two-way ANOVA showed no interaction between the quintiles of weight change and survey days on energy intakes (Figure 6.3). This was supported by the significantly higher energy intakes in quintiles 1 and 5 than in the other quintiles by survey days 6 and 7 ($P=0.05$, survey day 6. $P=0.02$, survey day 7. one-way ANOVA). Within each quintile, there was no difference in energy intake between the survey days (one-way ANOVA. $P>0.05$).

In Table 6.3, the effect of adjusting energy intakes on EI/BMR_{est} and the prevalence of underreporting is examined in men and women. When energy intakes were increased in those who lost weight (by the energy equivalent of the body weight loss), mean energy intake increased by 15% in both men and women while the prevalence of underreporting fell by one-third, from 24% to 15% in men and from 30% to 20% in women (Table 6.3). The cumulative effect of increasing energy intakes in underreporters who gained weight was an additional 2-3% increase in mean daily energy intakes while the prevalence of underreporting fell by a further one-third to 9% in men and 12.5% in women (Table 6.3). The final cumulative increase in energy intakes, to eliminate underreporting, increased total energy intakes by only 1-2%.

Figures 6.4 and 6.5 graphically show the increase in energy intakes in underreporters after adjusting intakes for weight loss, weight gain and to eliminate underreporting. These results are shown for all men and women underreporters and for those categorised as low, moderate or high activity. Taking the final adjusted energy intake as the 'true' energy intake in underreporters, it can be seen that 66% to 70% of energy intake was actually reported with 30% to 33% underreported (Figures 6.4 and 6.5). Of this underreported energy intake, 14 to 17% is explained by weight loss and can be

described as under eating. A further 10 to 11% can be truly described as underreporting as it is explained by weight gain. The final 5 to 7% cannot be explained by weight change. A similar pattern is seen when underreporters are categorised as low, moderate or high activity (Figures 6.4 and 6.5).

6.4 Discussion

Irish adults are gaining weight with an increase in the prevalence of obesity from 10-11% in 1989/1990 (Lee & Cunningham, 1990; Barker *et al.*, 1988) to 17.8% in 2000 (Irish Universities Nutrition Alliance, 2001). The average yearly increase in weight was calculated at 0.55kg in men and 0.33kg in women (McCarthy *et al.*, 2001). This translates into a small value when expressed as a weekly gain of approximately 0.01kg. While the mean weight loss in the NSIFCS population, over the food diary week, was also small (-0.05kg), the fact that a mean weight loss was seen in all men, all women, all age groups, in energy underreporters and in valid energy reporters is significant considering that, the Irish population are gaining weight. If this weight loss was sustained over a year, it would translate into a loss of 2.6kg of weight in the population. Respondents most likely to be in negative energy balance (i.e. losing weight) were excluded from this analysis - those dieting to lose weight and those who reported a reduced food intake as they were unwell during the food diary week. On the other hand, the three respondents who reported trying to gain weight were also excluded. Pregnant women and adolescents who are both likely to be in positive energy balance were not included in the original NSIFCS sample.

In the literature, all of the studies reviewed that reported weight changes in adults while recording food intake, reported a mean weight loss between -0.1kg and -1.0kg per week (Pannemans & Westerterp, 1993; deVries *et al.*, 1994; Raben *et al.*, 1995; Lissner *et al.*, 1989; Milne *et al.*, 1991; Lindroos *et al.*, 1993; Kempen *et al.*, 1995; Sawaya *et al.*, 1996; Martin *et al.*, 1996; Taren *et al.*, 1999; Goris *et al.*, 2001a; 2001b; Goris *et al.*, 2000; Goris & Westerterp, 1999). The sample sizes in most of these studies (n = 20 to 64) are remarkably smaller than the 921 respondents in the present study. deVries *et al.*, (1994) reported a mean weight loss in 269 adults of -0.32kg during week 1 of an experimental diet where food intakes were observed. The energy content of the experimental diet was originally calculated at 10% higher than reported energy intake from 3 day food records. During week 2 of the experimental diet, respondents lost an average of -0.15kg and energy intakes were increased in units of 0.5MJ/day to maintain

body weight. This increased energy intake was provided from week 3 onwards and respondents continued to lose -0.05kg/week until the end of the study (3 to 6 weeks later). There are two studies, both in adolescents, which report a mean weight gain during food intake recording. Obese and non obese adolescents gained an average of 0.18kg and 0.04kg per week respectively while keeping a food diary for 14 days (Bandini *et al.*, 1990). In another study, 15 year old boys gained 0.12kg and 15 year old girls lost 0.09kg while keeping a 7 day food record (Bratteby *et al.*, 1998). In both of these studies, energy intake was however underreported compared to TEE measured by DLW, despite the weight gain. In a series of studies, Goris and colleagues compared weight changes over a week when food intake was not recorded for comparison with a recording week in adults. A mean weight gain of 0.62kg was reported in 30 adults during the non recording week compared to -0.26kg during the food intake recording week (Goris *et al.*, 2001a). In 34 other adults, the non recording week weight change was +0.23kg compared to -0.26kg during the recording week (Goris *et al.*, 2001b). In 30 obese men, there was no weight change during the non-recording week while there was a mean weight loss of -1.0kg during the recording week (Goris *et al.*, 2000). In a study of 24 dietitians, body weight increased by an average of 0.1kg over the non-recording week and weight decreased by -0.6kg when food intake was recorded (Goris & Westerterp, 1999).

Measuring body weights in a large national food consumption survey, where respondents are met in their own homes or workplaces, is much more challenging than measuring body weights in a clinic or laboratory. In this study, fieldworkers were trained in taking all of the body measurements and followed an agreed protocol that was listed on the sheet for recording the anthropometric measurements. To ensure compliance with the protocol, the fieldworker ticked that each of the conditions was met. These included light clothing, without shoes, after voiding and a duplicate measurement. In addition, fieldworkers recorded the time at which each weight was taken and the floor surface to ensure that both body weights (before and after the food diary) were taken at the same time of the day and on the same floor surface. Only measurements taken 6 to 11 days apart were included in this analysis. Fieldworkers met respondents on 4 occasions: day 0, day 2, day 4 or day 5 and day 8, with the intention of measuring body weight on day 0 and day 8. The mean number of days between the two body weights in the 921 respondents in this analysis was 9 days.

When respondents were divided into quintiles of weight change over the food diary week, there were some trends, but no significant differences, in energy intake, EI/BMR_{est}, ePAL or the prevalence of underreporting between the quintiles. Energy underreporting clearly occurred in respondents in each category of weight change in both men and women. Energy underreporting in those who lost weight suggests reduced food intake during the survey while energy underreporting in those who gained weight suggests that not all foods eaten were recorded. Taren *et al.*, (1999) reported a mean weight gain of 0.12kg over 9 days in underreporters (defined as EI less than TEE as measured by DLW). Energy intakes were measured by three non consecutive 24 hour recalls over the 9 days when total energy expenditure was measured. In the same study, there was a mean weight loss of -0.25kg in overreporters (defined as EI greater than TEE). Although not mentioned by the author, this suggests that the three 24 hour recalls didn't reflect energy intake over the 9 days or that the weight gain in underreporters points towards more underrecording rather than undereating. In the study by Bandini *et al.*, (1990), obese and non obese adolescents gained weight while energy intakes were less than total energy expenditure measured by doubly labelled water. When energy intake was adjusted for weight change, the adjusted mean value was still less than TEE. When the adolescents were further classified according to whether they lost, gained or maintained weight, the non-obese group who lost weight were the only group in which adjusted energy intake matched TEE. To this author, this suggests that the underreported energy intakes in the other groups were not only due to changed eating patterns measured by weight gain and weight loss.

The percentage of total energy and food energy intake from each of the macronutrients was examined across each of the quintiles of weight change. This showed that there were no differences in the proportion of energy intakes from the macronutrients between those who lost, gained or maintained weight during the survey (data not shown). In order to see if there were any obvious characteristics associated with weight gain, weight loss or weight maintenance, a whole series of variables were examined across the quintiles of weight change in men and women: age, smoking status, social class, restrained eating (van Strien *et al.*, 1986), body mass index, waist circumference, attitudes towards health, perception of the survey and weight status over the previous five years (data not shown). There were no significant differences in these variables between the quintiles with the exception of waist circumference in women where those who gained weight (quintiles 4 and 5) had greater waist circumferences than those who

lost the most weight (quintile 1) at 83.4cm and 81.3cm compared to 77.7cm (P=0.021, ANOVA).

Day-to-day variations in energy intakes are expected so the purpose of examining energy intakes in each quintile on each survey day is to determine if there were differences in intakes over the 7 days of the survey according to weight change. In a previous analysis of the NSIFCS, the present author showed that, in the full population sample (n = 1379) that there was no significant effect of survey duration on either energy intakes or on EI/BMR_{est} (McGowan *et al.*, 2001) suggesting consistent food intake recording over the survey week. Energy intakes and EI/BMR_{est} were higher on Fridays and Saturdays than on the other survey days. Both of these findings have been reported by others (Black *et al.*, 1995; Harrington, 2001).

In men, there was no overall significant interaction of survey day and weight change on energy intakes (Figure 6.2). In quintile 1 (those who lost the most weight), energy intake decreased significantly with increasing survey duration. This suggests that, in men who lost the most weight (who also had the highest prevalence of underreporting), survey duration did affect the quality of food intake reporting and/or adherence to usual eating patterns. In women also, there was no significant interaction of survey day and weight change on energy intakes (Figure 6.3) but there was a significant effect of quintile of weight change on energy intake (two-way ANOVA. Figure 6.3). When energy intakes in women were examined for all 7 days (Table 6.2) there were no significant differences noted (one way ANOVA). This suggests that the significant effect of weight change on energy intake was related to some survey days only. This is supported by the finding (using one way ANOVA) that energy intakes on days 6 and 7 were significantly higher in quintiles 1 and 5 than in the other quintiles. This finding readily makes sense in quintile 5 i.e. those who gained the most weight had higher energy intakes than those that either maintained or lost weight during the survey. It however appears counterintuitive that those who lost the most weight (quintile 1) had higher energy intakes than those with the least weight change (quintiles 2, 3 and 4). This is likely reflecting the fact that underreporting occurred in all quintiles and that while undereating clearly happened in those who lost the most weight, underrecording is the more likely reason for low energy intakes in quintiles 2,3 and 4. In addition underrecording, in these quintiles, may have increased by survey days 6 and 7.

Energy intakes were adjusted in 3 stages. In the first place, energy intakes were adjusted for weight loss in all respondents, as those expected to lose weight had been excluded from the analysis. It is of course possible that some of the 420 respondents who lost weight during the survey would have lost weight even if they didn't participate in the survey. These are likely to be in the minority as the weight status of the Irish population is increasing and those expected to lose weight had been excluded. Secondly, energy intakes were increased in underreporters who gained weight, on the basis that the combination of invalid energy intakes and weight gain suggests that the energy equivalent of the weight gained had not been included in the food diary. Thirdly, energy intakes were increased in those still classified as underreporters (i.e. after the two previous adjustments) to the energy intake at which EI/BMR_{est} met the relevant cut-off. These last two adjustments assume that underreporters were correctly identified. The cut-offs for EI/BMR_{est}, used to identify underreporters, varied according to the activity level of the respondent. In 'low activity' men and women, the cut-offs were 1.05 and 1.06 respectively. It is virtually impossible that there were valid energy reporters with an EI/BMR_{est} below these cut-offs as they represent energy intakes just 5% and 6% greater than BMR. The cut-offs for EI/BMR_{est} were 1.21 and 1.11 for 'moderate activity' men and women respectively and were 1.42 and 1.23 for 'high activity' men and women. If respondents were classified at a higher activity level that their 'true' activity level and if their EI/BMR_{est} fell between the cut-offs for the two levels, then they were classified incorrectly as underreporters. The total number of respondents that this possibly applied to was 32 men and 22 women. The cut-offs for both moderate and heavy activity were still modest multiples of BMR ranging from 11% to 42% above BMR.

In this study, the energy content of 1kg body weight was taken as 30MJ (75% fat mass at 38.3MJ/kg, 25% fat free mass of which 73% is water, at 3.5MJ/kg) (Westerterp *et al.*,, 1995). This value was chosen as it had been used in the studies by Goris and colleagues, which represent the largest series of studies on undereating and underrecording of food intakes in the literature by the same author (Goris *et al.*, 2001a; 2001b; Goris *et al.*, 2000; Goris & Westerterp, 1999). It was also used by Kempen *et al.*, (1995). Other authors have used similar values: 1kg of adipose tissue equivalent to 7600kcal (32MJ) (Bandini *et al.*, 1990), 1kg body weight equivalent to 29MJ (Milne *et al.*, 1991), 1kg body weight equivalent to 7000kcal (29.5MJ) (Lindross *et al.*, 1993). Pannemans & Westerterp (1993) calculated the energy cost of 1 kg of body weight as

43.15MJ, based on the slope of the regression line when weight loss was compared to the difference in EI and TEE in elderly men and women. Using a similar approach, Lissner *et al.*, (1989) found that 1kg of body weight was the equivalent of 6292kcal (26.5MJ). This value (6292) was the regression co-efficient for mean daily weight change from a regression equation that predicted observed energy intake. Some studies did not report the assumed energy value of body weight (Raben *et al.*, 1995; Martin *et al.*, 1996).

In the present study, the total adjustments to energy intake represented an increase of 2.0MJ/day in men (18% increase) and 1.5MJ/day in women (19.5% increase). In underreporters, the increases were greater: 3.2MJ/day in men (40.5% increase) and 2.1MJ/day in women (36% increase). It is difficult to compare these results with others in the literature as results have been reported in different ways and in varying levels of detail. Energy intakes increased by 27% in obese women when adjusted for weight loss (-0.04kg/day) over a 4 day food record (Lindross *et al.*, 1993) and by 30% in 63 women taking part in a intervention study over 14 to 63 days (Lissner *et al.*, 1989). In other studies the energy cost of the change in weight has been presented. Reported EI was 0.8MJ/day lower than EI adjusted for weight loss in 48 men who completed a 7 day food record (Raben *et al.*, 1995). There was an energy deficit of 10% between reported EI and EI adjusted for weight loss in 40 men who completed two 7 day records (Milne *et al.*, 1991) while 24% of the difference between EI and TEE was accounted for by weight loss in 29 women (Martin *et al.*, 1996) and 70-100% of the difference between EI and TEE was accounted for by undereating (measured by weight loss) in 2 other studies (Goris *et al.*, 2001; Goris & Westerterp, 1999).

Of all the studies reviewed that adjusted energy intake for weight change, only two appear to have corrected energy intake for weight gain (Lissner *et al.*, 1989; Bandini *et al.*, 1989) and both of these studies decreased energy intake for weight gain. Lissner *et al.*, (1989) did acknowledge that 71% of the weight changes were actually losses and therefore overall energy intakes increased after adjustment for weight change. Bandini *et al.*, (1989) measured EI and TEE (DLW) in 55 adolescents over 14 days. The mean change in weight was a gain of 0.37kg in the obese adolescents and 0.08kg in the non-obese adolescents. Despite the gain in weight, EI was less than TEE. EI decreased by 2% in the non-obese and by 10% in the obese when adjusted for weight gain, which further increased the discrepancy between EI and TEE.

The Goldberg equation (Goldberg *et al.*, 1991; Black, 2000) is most frequently used to identify underreporters. The upper 95% confidence limit of agreement between EI/BMR and PAL, calculated from the equation, is the cut-off for EI/BMR above which energy intake is deemed overreported. Before any adjustments to energy intake, less than 1% (n = 7) of the sample (n = 921) overreported their energy intake. This increased to 5% (n = 43) when energy intakes were adjusted. All of those who became overreporters lost 1.0kg of weight of more with subsequent increases in energy intake of 30MJ/week or more (4.3MJ/day). The fact that energy intakes increased beyond what is considered valid in 36 respondents (43 minus 7 originally identified as overreporters) suggests that either their energy expenditure increased during the week or that body weight measurements were incorrect in this group. All other adjusted energy intakes were in the expected valid range for EI/BMR_{est}.

Assuming the total adjusted energy intake in underreporters is their 'true' intake, approximately two-thirds of energy intake was reported and, of the one-third not reported, approximately 50% was due to undereating and 50% due to underrecording (Figures 6.4 and 6.5). The proportion of undereating and underrecording was broadly similar in underreporting men and women in each of the activity categories. The highest proportion of underrecording was in high activity men and women. This finding may be true or it may indicate overreporting of activity. If activity was overreported, then the cut-off for EI/BMR_{est} was too high and energy intakes were increased to a greater extent than necessary.

The proportional increases in energy intake after adjustment for weight loss, weight gain and to eliminate underreporting cannot be extrapolated to either macronutrient or micronutrient intakes as all foods, and hence nutrients, are unlikely to be underreported or under-eaten to the same degree. There is evidence of higher intakes of protein and lower intakes of fat in underreporters compared to others (Körtzinger *et al.*, 1997; Price *et al.*, 1997; Briefel *et al.*, 1997; Becker *et al.*, 1999).

This study shows that it is important, and feasible, to estimate energy balance in large food surveys. While there was a mean weight loss in this population, there were energy underreporters who gained weight as well as those who lost weight. The energy adjustment analysis suggested that one-third of energy intake was not reported of which 50% was due to reduced food intakes and 50% due to under recording of foods eaten.

In the last decade, our understanding of the reasons for and the consequences of invalid energy intakes have increased greatly. The next challenge is to improve dietary survey methodologies to minimise these errors.

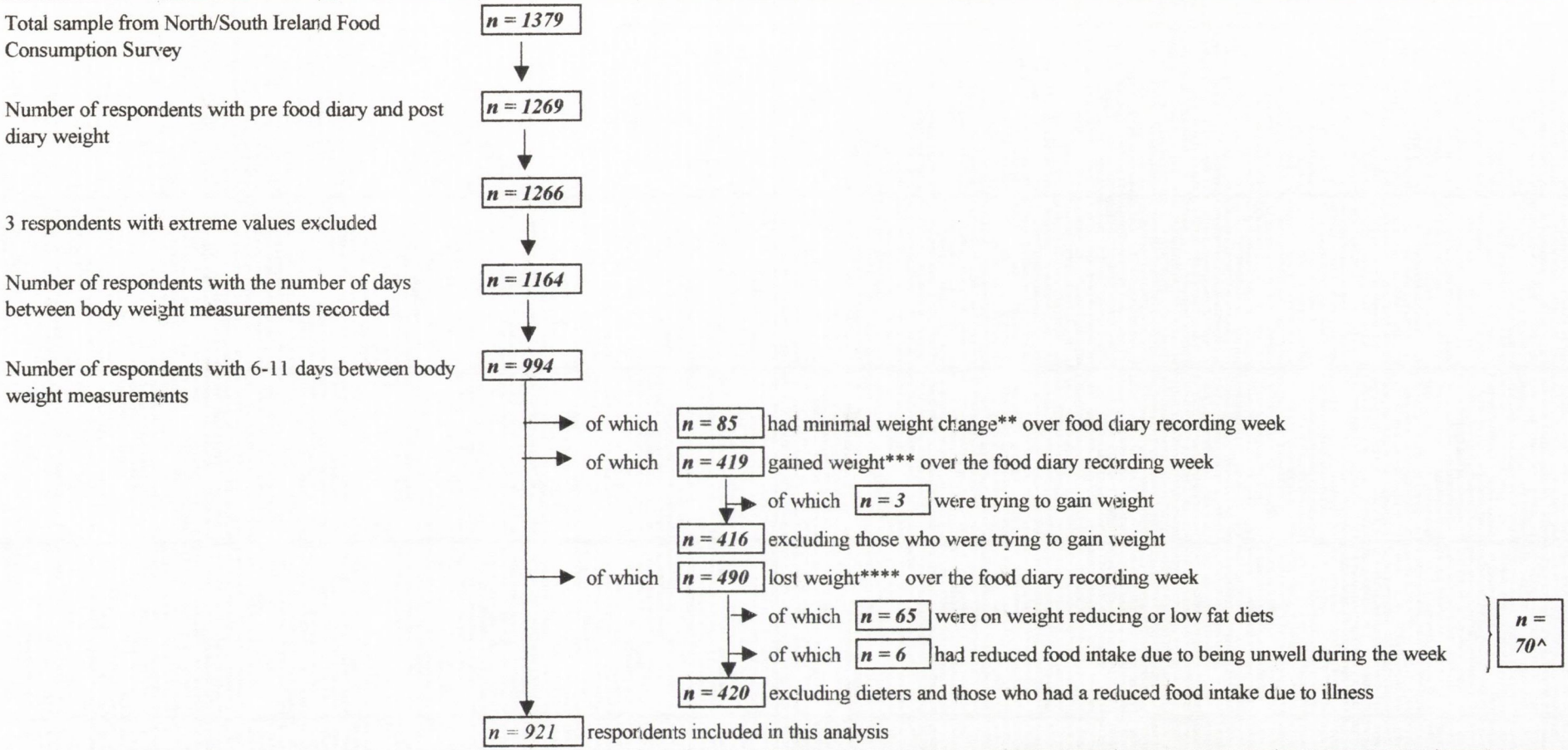
Table 6.1 Body weight differences in kilograms over the food diary week in 921 respondents from the North/South Ireland Food Consumption Survey.

		Weight difference (kg)		Weight status*		
				Lost	Gained	No change
	n	Mean	(SD)	*n* (%)	*n* (%)	*n* (%)
All	921	-0.05	(0.85)	420 (46%)	416 (45%)	85 (9%)
Men						
All ages (18-64yrs)	441	-0.08	(0.96) [NS]	199 (45%)	202 (46%)	40 (9%)
18-35yrs	179	-0.13	(1.04) [a]	80 (45%)	81 (45%)	18 (10%)
36-50yrs	147	-0.03	(0.94) [a]	68 (46%)	68 (46%)	11 (7%)
51-64yrs	115	-0.08	(0.84) [a]	51 (44%)	53 (46%)	11 (10%)
Women						
All ages (18-64yrs)	480	-0.03	(0.74) [NS]	221 (46%)	214 (45%)	45 (9%)
18-35yrs	186	-0.05	(0.72) [a]	81 (44%)	86 (46%)	19 (10%)
36-50yrs	191	-0.01	(0.80) [a]	87 (46%)	83 (43%)	21 (11%)
51-64yrs	103	-0.03	(0.68) [a]	48 (47%)	50 (48%)	5 (5%)
Underreporters						
All	250	-0.10	(0.83)	121 (48%)	106 (42%)	23 (9%)
Men	106	-0.15	(1.02) [NS]	52 (49%)	46 (43%)	8 (8%)
Women	144	-0.06	(0.65) [NS]	69 (48%)	60 (42%)	15 (10%)

* Weight loss defined as $\geq$ 0.1kg loss. Weight gain defined as $\geq$ 0.1kg gain. No change defined as < 0.1kg difference.

[NS] mean weight change not significantly different between men and women (t-test).

[a] mean weight change not significantly different between age groups for men and women (ANOVA).



** minimal weight change defined as < 0.1kg difference; *** weight gain defined as ≥ 0.1kg gain; **** weight loss defined as ≥ 0.1kg loss.

^ n=70 rather than 71 because one subject was both on a weight reducing diet and reduced food intake due to illness during the recording week.

Figure 6.1 Flow chart describing the sample size from the North South Ireland Food Consumption Survey included in analysis of changes in body weight while completing the 7 day food diary

Table 6.2 Weight differences and energy intakes between quintiles of weight change, over the food diary recording week, in men and women from the North/South Ireland Food Consumption Survey.

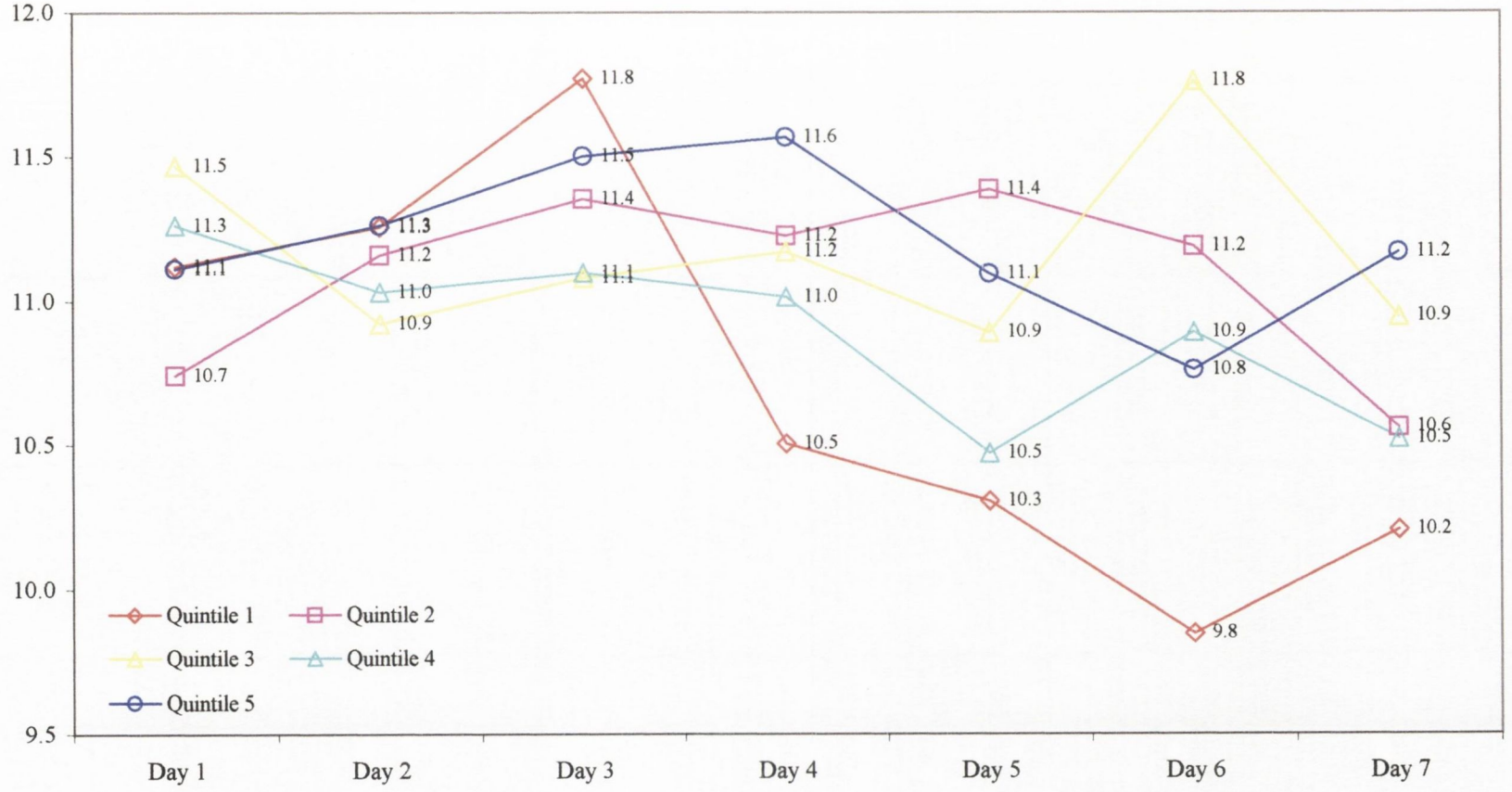
		Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5		Total
Men		*n = 81*		*n = 93*		*n = 83*		*n = 98*		*n = 86*		*n = 441*
Weight difference (kg)*	Mean (SD)	-1.51 (0.66)	a	-0.48 (0.21)	b	-0.02 (0.08)	c	0.29 (0.14)	d	1.20 (0.55)	e	-0.08 (0.96)
	Median	-1.30		-0.50		0.00		0.30		1.05		0.00
Energy Intake (MJ)	Mean (SD)	10.7 (2.7)		11.1 (2.5)		11.2 (3.8)		10.9 (2.8)		11.2 (2.9)	ns	11.0 (2.9)
EI/BMR_{est}	Mean (SD)	1.39 (0.38)		1.44 (0.34)		1.51 (0.52)		1.43 (0.38)		1.46 (0.41)	ns	1.44 (0.41)
ePAL[#]	Mean (SD)	1.86 (0.46)		1.71 (0.36)		1.84 (0.50)		1.83 (0.42)		1.84 (0.45)	ns	1.81 (0.44)
Underreporters[#]	(% of each quintile)	32%		22%		20%		23%		23%	ns	24%
Women		*n = 98*		*n = 93*		*n = 102*		*n = 88*		*n = 99*		*n = 480*
Weight difference (kg)*	Mean (SD)	-1.02 (0.43)	a	-0.36 (0.13)	b	-0.01 (0.09)	c	0.27 (0.09)	d	0.98 (0.54)	e	-0.03 (0.74)
	Median	-0.90		-0.30		0.00		0.30		0.80		0.00
Energy Intake (MJ)	Mean (SD)	7.7 (1.9)		7.4 (1.7)		7.6 (2.5)		7.6 (1.9)		8.2 (1.8)	ns	7.7 (2.0)
EI/BMR_{est}	Mean (SD)	1.32 (0.33)	ab	1.27 (0.32)	b	1.31 (0.45)	b	1.29 (0.33)	b	1.42 (0.35)	a	1.32 (0.36)
ePAL[#]	Mean (SD)	1.69 (0.29)		1.65 (0.25)		1.71 (0.28)		1.68 (0.23)		1.70 (0.27)	ns	1.68 (0.27)
Underreporters[#]	(% of each quintile)	30%		30%		36%		33%		21%	ns	30%

* Significant difference in weight change between men and women in quintile 1 and 2 ($P<0.001$) and quintile 5 ($P=0.007$).

[#] sample size for ePAL and underreporters in each quintile for Men as follows: Quintile 1 *n* = 79; Quintile 2 n = 92; Quintile 3 n = 79; Quintile 4 n = 94; Quintile 5 n = 83 and for Women as follows: Quintile 1 n = 95, Quintile 2 n = 93, Quintile 3 n = 98, Quintile 4 n = 85, Quintile 5 n = 96.

[abcde] Significant differences in weight difference between quintiles of weight change ($P<0.001$ ANOVA mean weight difference men and women) ($P< 0.05$ ANOVA EI/BMR_{est} in women only).

[ns] No significant difference in variable between quintiles of weight change ($P>0.05$) (ANOVA/Chi Square).

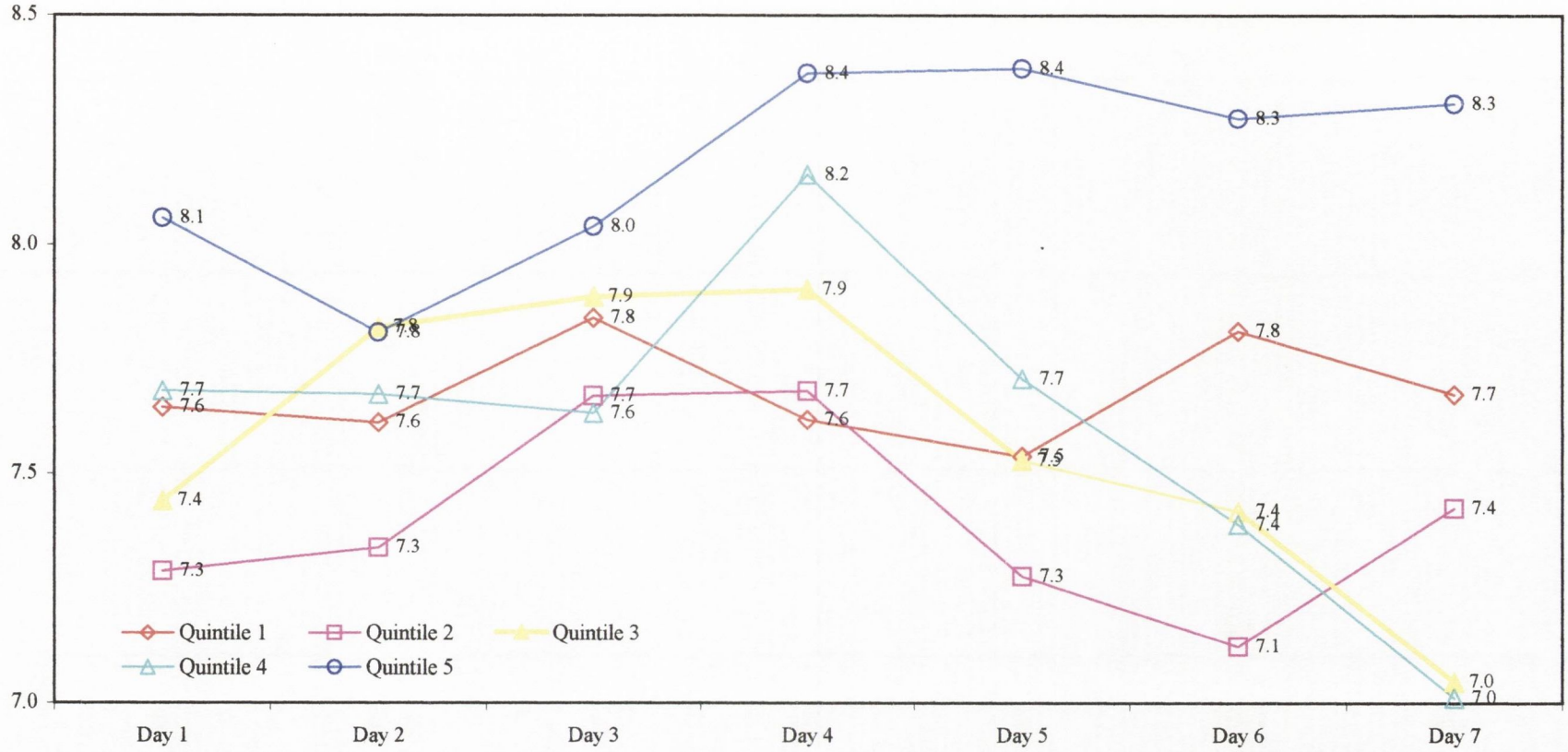


Two Way ANOVA: no significant effect of survey day, quintile of weight change or interaction of both on energy intakes ($P>0.05$).

One Way ANOVA: significant decrease in energy intake in quintile 1 with increasing survey days ($P=0.03$). No differences in other quintiles ($P>0.05$).

One Way ANOVA: no significant difference in energy intake on each survey day between quintiles of weight change ($P>0.05$).

Figure 6.2 Mean daily energy intakes (MJ) in men according to survey day and quintile of weight change over the survey period.



Two Way ANOVA: significant effect of quintiles on energy intake (P <0.001). No significant effect of increasing survey days on energy intake (P >0.05). No significant interaction between quintiles and survey days (P >0.05).
One Way ANOVA: no significant difference in energy intake between survey days within each quintile (P >0.05).
One Way ANOVA: significantly higher energy intakes in quintiles 1 and 5 on day 6 (P =0.05) and day 7 (P =0.02) than in other quintiles.

Figure 6.3 Mean daily energy intakes (MJ) in women according to survey day and quintile of weight change over the survey period.

Table 6.3 The effect of adjusting energy intakes (MJ) in 921 respondents, for weight loss and weight gain in underreporters during the food diary week, on mean energy intakes, mean EI/BMR_{est} and the prevalence of underreporting, and the subsequent additional energy required to eliminate underreporting.

	All Men			Underreporters (Men)			All Women			Underreporters (Women)		
	n = 441			*n = 106*			*n = 480*			*n = 144*		
	Energy (MJ) Mean (SD)	EI/BMR_{est} Mean (SD)	UR n (%)	Energy (MJ) Mean (SD)	EI/BMR_{est} Mean (SD)	UR n (%)	Energy (MJ) Mean (SD)	EI/BMR_{est} Mean (SD)	UR n (%)	Energy (MJ) Mean (SD)	EI/BMR_{est} Mean (SD)	UR n (%)
Original data	11.0 (2.9)	1.45 (0.41)	106 (24%)	7.9 (1.6)	1.00 (0.20)	106 (100%)	7.7 (2.0)	1.32 (0.36)	144 (30%)	5.8 (1.1)	0.95 (0.15)	144 (100%)
+ E.I. increased according to weight loss in all	12.7 (3.9)	1.66 (0.53)	67 (15%)	9.9 (3.3)	1.25 (0.43)	67 (63%)	8.9 (2.7)	1.53 (0.48)	97 (20%)	7.0 (2.1)	1.14 (0.32)	97 (67%)
+ E.I. increased according to weight gain in underreporters	13.0 (3.8)	1.70 (0.51)	40 (9%)	11.1 (3.6)	1.41 (0.46)	40 (38%)	9.2 (2.6)	1.58 (0.46)	60 (12.5%)	7.9 (2.3)	1.30 (0.36)	60 (42%)
+ E.I. required to eliminate underreporting	13.2 (3.6)	1.72 (0.48)	0 (0%)	11.9 (3.0)	1.50 (0.38)	0 (0%)	9.3 (2.4)	1.60 (0.43)	0 (0%)	8.3 (1.9)	1.37 (0.30)	0 (0%)

+ E.I. = plus energy intake.

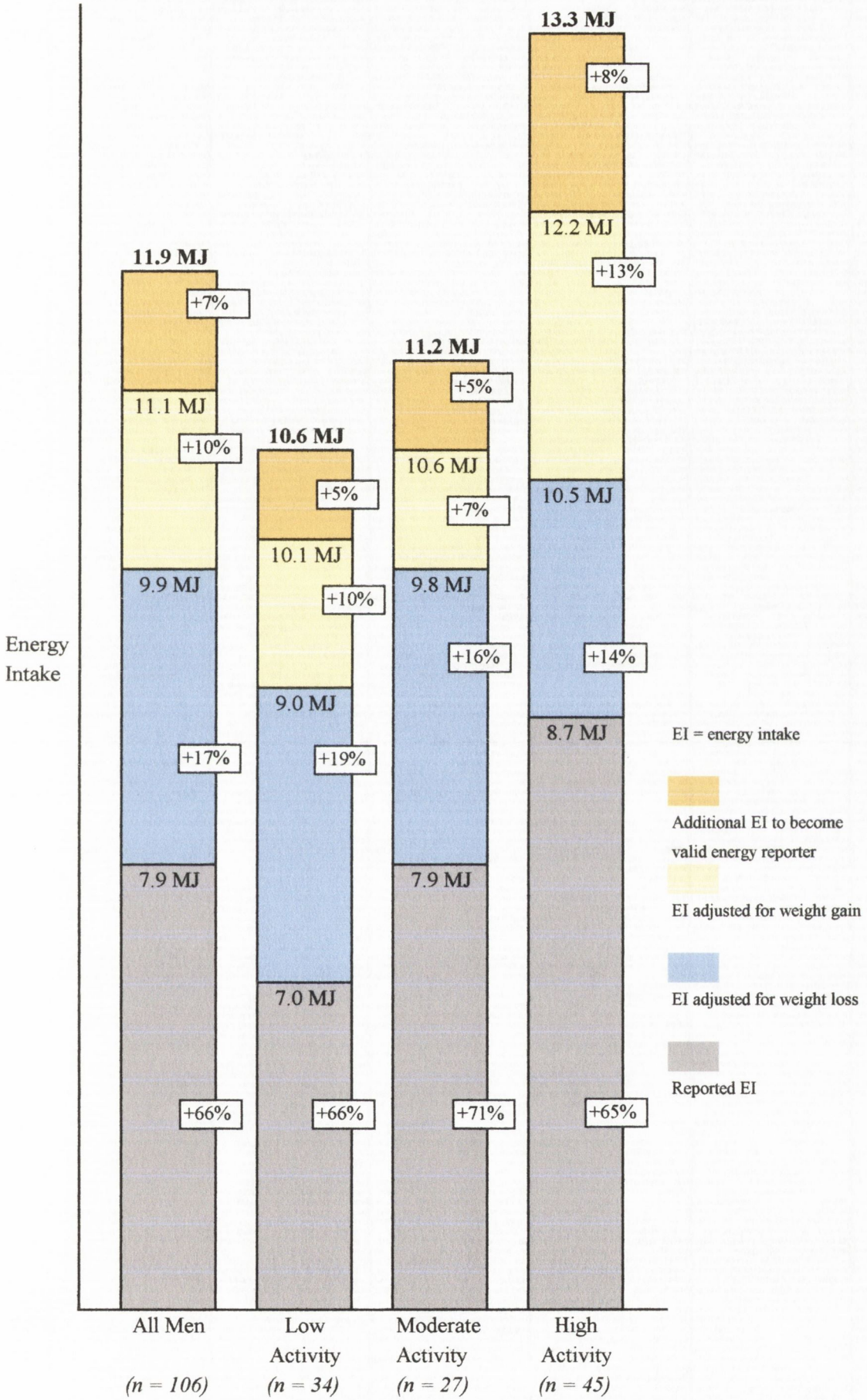


Figure 6.4 Energy intakes (MJ/day) in underreporting men adjusted for weight gained or lost during food diary period and additional energy required to be classified as valid energy reporters.

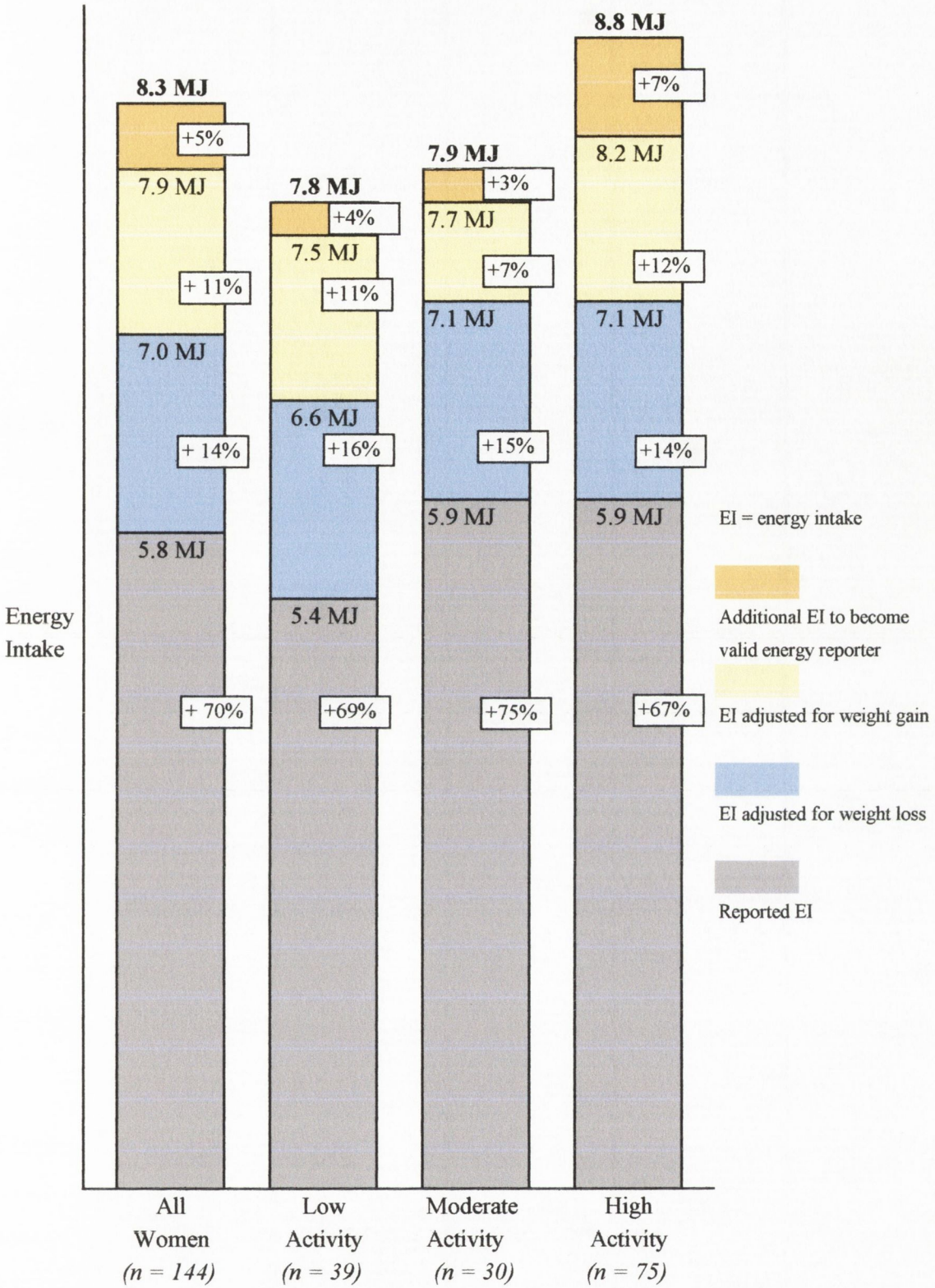


Figure 6.5 Energy intakes (MJ/day) in underreporting women adjusted for weight gained or lost during to food diary period and additional energy required to be classified as valid energy reporters.

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Chapter 7

General Discussion

The North/South Ireland Food Consumption Survey (NSIFCS) database of food and nutrient intakes, on a representative sample of 1379 Irish adults, along with the anthropometric measurements, physical activity and health and lifestyle information, provided extensive data for the rigorous examination of energy underreporting presented in this thesis. The findings are relevant to all other analyses of the NSIFCS data and also contribute to the wider research on energy underreporting, both of which will be discussed presently.

Relevance of findings to analysis of NSIFCS

The findings in this thesis highlight the need to examine the influence of energy underreporting on the interpretation of all food and nutrient results from the NSIFCS, especially the relationship between food intakes, nutrient intakes and health. The present analysis provides investigators with an improved method to identify energy underreporters in the NSIFCS, by including population-specific physical activity levels in the calculation of cut-offs for EI/BMR_{est} (Goldberg *et al.*, 1991; Black 2000a). In addition, the analysis on body weight changes gives an estimate of the relative contribution of undereating and underrecording to overall energy underreporting in the NSIFCS. These findings can be used to help interpret the influence of underreporting on food and nutrient intakes in any further analysis of the NSIFCS.

The estimated physical activity levels (ePALs), calculated in this research, are the first estimates of PAL in a large representative sample of Irish adults. As the mean ePALs, for men and women in each of the body mass index categories, are comparable to doubly labelled water measures of PAL, these values can be used with confidence in further analyses. In addition, as ePAL represents all activities, not just the work, recreation and selected home activities that were included in the original calculation of total METS, it can be used to comprehensively analyse physical activity in the Irish population.

Relevance of findings to research on energy underreporting

Most of the published research on energy underreporting can be categorised as (i) methods to improve the identification of energy underreporters, (ii) characterising energy underreporters, (iii) understanding the underlying mechanisms and (iii) evaluating the influence of energy underreporting on the interpretation of food and

nutrient intakes. The findings presented in this thesis contribute to each of these areas of research.

In the first place, the NSIFCS showed that including a physical activity questionnaire and measuring body weight changes while completing a 7 day food diary is feasible in large food intakes studies. The physical activity data were used to improve the sensitivity of the Goldberg equation in identifying underreporters (Black, 2000b) and the changes in body weight were used to estimate the impact of undereating and underrecording on energy underreporting. The techniques described can easily be used in other food intake studies.

While the physical activity questionnaire was not initially designed to calculate a physical activity level (PAL) for each respondent, this research shows that the questionnaire can be used in this way. In chapter 4, some suggestions are made to improve aspects of the questionnaire administration and analysis, which would improve the capability of the questionnaire in calculating PALs at an individual level. This study is the first large study to use population-specific PALs in the Goldberg equation to calculate cut-offs for EI/BMR_{est}. Goldberg and Black (Goldberg *et al.*, 1991, Black *et al.*, 1997, Black 2000b) have repeatedly recommended that physical activity data are collected in food intake studies to choose an appropriate PAL against which EI/BMR_{est} can be compared. The technique used in this study is a clear example of how population-specific PALs can be used to identify energy underreporters in a large food intake study.

The above approach identified a greater prevalence of energy underreporting in the NSIFCS (30%), than earlier, when EI/BMR_{est} was compared to a standard PAL of 1.55 (19%) (Goldberg *et al.*, 1991, Black 2000a), while women and those were overweight/obese remained most likely to underreport their energy intakes. The higher prevalence of energy underreporting impacted on the interpretation of the adequacy of nutrient intakes, especially fat and iron intakes in women. This highlighted the importance of adequately recognising all energy underreporters in food intake studies.

The final analysis in this thesis (chapter 6) showed how the simple technique of adjusting energy intakes for changes in body weight over the survey period can be used as an estimate of the relative contributions of both undereating and underrecording of

food intakes to energy underreporting. It also highlighted that it is incorrect to assume energy balance during food intake studies. The mean weight loss of 0.05kg in the NSIFCS was calculated after those expected to lose weight were excluded i.e. dieters and those who were ill.

In agreement with other authors (Smith *et al.*, 1994; Pryer *et al.*, 1995; Macdiarmid & Blundell, 1998), this study shows that energy underreporting effects the interpretation of nutrient intakes and nutrient adequacy in a population. Excluding underreporters is not the ideal solution as it automatically excludes a sizeable proportion of respondents (30% in the NSIFCS) and alters the characteristics of the population. Adjusting energy intakes is not an ideal solution either, as this study and others (Livingstone & Black, 2003) provide evidence that foods, and hence nutrients, are differentially underreported. The solution can only be to improve all aspects of dietary survey methodology to reduce the prevalence of energy underreporting. In this study, energy underreporting was considered in the planning stage. Various aspects of the survey methodology were included to help examine energy underreporting with the inclusion of a physical activity questionnaire, a restrained eating questionnaire (van Strein *et al.*, 1986), and an evaluation questionnaire. In addition, body weight was measured at the beginning and end of the food diary recording week. A protocol for quantifying foods was agreed to ensure that different foods could be quantified as accurately as possible. Fieldworkers were trained on all aspects of the survey methodology and a fieldworker manual was compiled. Furthermore, fieldworkers visited respondents on four occasions to clarify and quantify foods and drinks recorded and to check for omissions. These visits also offered an opportunity to motivate respondents to continue completing the food diary. Despite all these aspects of the survey methodology, energy intakes were underreported in 30% of the population.

The terms used to describe energy underreporting e.g. misreporting, low energy reporting, implausible energy reporting, all imply that respondents intentionally or unintentionally misrepresent their food intake. It is likely that the actual survey methodology strongly influences the respondent's ability to correctly describe their habitual food intake. Food intake recording is influenced by recall/memory, literacy and numerical skills, ability to quantify foods eaten and the motivation of both the respondent and fieldworker. With recent limited evidence of variations in the validity

of energy intake according to fieldworkers (Slimani *et al.*, 2000), this is an area that requires further research.

In conclusion, collecting accurate food and nutrients intakes is a challenging aspect of nutrition research. Further challenges lie ahead to continue improving the methods by which underreporters are identified and to understand the mechanisms behind energy underreporting including the aspects of dietary survey methodology that contribute to the whole phenomenon of energy underreporting.

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Appendix I

Physical Activity Questionnaire

Cluster ___/___

Respondent ___/___

Date of Birth__ __/__ __/19__ __

Fieldworker ___/___

Physical Activity Questionnaire

THE QUESTIONNAIRE IS DIVIDED INTO 3 SECTIONS

- **Section A** asks about your physical activity patterns in and around the house.
- **Section B** is about travel to work and your activity at work. It may be skipped by people who have not worked at any stage during the past year.
- **Section C** asks about recreations that you may have engaged in during the past year.

What is your date of birth? ☐☐/☐☐/☐☐ (day / month / year)

What is today's date? ☐☐/☐☐/☐☐ (day / month / year)

Your sex *(Please tick ✓ appropriate box)*? Male ☐ Female ☐

Section A HOME ACTIVITIES

GETTING UP AND GOING TO BED

*Please put a time in **each** box*

	Average over the past year	
	At what time do you normally get up?	At what time do you normally go to bed?
On a weekday		
On a weekend day		

GETTING ABOUT — Apart from going to work

*Please put a tick (✓) on **every** line*

	No	Yes
I travel by car most or all of the time	☐	☐
I travel by public transport most or all of the time	☐	☐

	Average number of journeys each week *Please insert a number*	Average distance of each journey					
		less than 0.5 miles	0.5 to 1.5 miles	1.5 to 2.5 miles	2.5 to 3.5 miles	3.5 to 5.5 miles	More than 5.5 miles
By bicycle							
Walking							

TV OR VIDEO VIEWING

*Please put a tick (✓) on **every** line*

Hours of TV or Video watched per day	Average over the past year					
	None	less than 1 hour a day	1 to 2 hours a day	2 to 3 hours a day	3 to 4 hours a day	More than 4 hours a day
On a weekday before 6 pm						
On a weekday after 6 pm						
On a weekend day before 6 pm						
On a weekend day after 6 pm						

STAIR CLIMBING AT HOME

*Please put a tick (✓) on **every** line*

Number of times you climb up a flight of stairs (approx 10 steps) each day at home	Average over the past year					
	None	1 to 5 times a day	6 to 10 times a day	11 to 15 times a day	16 to 20 times a day	More than 20 times a day
On a weekday						
On a weekend day						

ACTIVITIES IN AND AROUND THE HOME

*Please put a tick (✓) on **every** line*

Approximate number of hours each week	Average over the past year						
	None	Less than 1 hour a week	1 to 3 hours a week	3 to 6 hours a week	6 to 10 hours a week	10 to 15 hours a week	More than 15 hours a week
Preparing food, cooking and washing up							
Shopping for food and groceries							
Shopping and browsing in shops for other items (e.g. clothes ,toys)							
Cleaning the house							
Doing the laundry and ironing							
Caring for pre-school children or babies at home (not as paid employment)							
Caring for handicapped, elderly or disabled people at home (not as paid employment)							

Section B ACTIVITY AT WORK

Please answer this section **only** if you have been in paid employment at any time during the past year or you have done regular, organised voluntary work.

If not please go to page 9

TYPES OF WORK DURING THE PAST YEAR

- We would like to know what full or part-time jobs you have done in the past year.
- You may have held a single job or have held two or more jobs at once.
- If you have changed responsibilities with the same employer, you should enter it as a change of job **only** if it entailed a substantial change in physical effort.

EXAMPLE

Someone who worked full-time for 6 months, then retired, rested for 3 months and then started a voluntary job for 6 hours a week, would complete the questions as follows.

	Job 1	Job 2	Job 3
Name of occupation	~~nurse~~	~~shop work~~	
How many hours **per week** do you usually work?	~~38~~	6	
For how many months in the past year did you do this work?	6	3	

EXAMPLE

What jobs have you held in the past year, and how many months in the year did you do them?

Please complete EACH line

	Job 1	Job 2	Job 3
Name of occupation			
How many hours **per week** did you usually work?			
For how many months in the past year did you do this work?			

ACTIVITY LEVELS AT YOUR WORK

Now we would like you to take the total number of hours you worked per week in each job and divide them up according to your activity level.

First of all, read each of the following categories and tick either the **Yes** or **No** box.

Then go back through the list and record the number of hours per week that you spent on each activity.

The number of hours in each activity should add up to the number of hours that you worked in each job, as you stated on page 5.

Please complete EACH line

	Job 1			Job 2			Job 3		
	No	Yes	Hours	No	Yes	Hours	No	Yes	Hours
Sitting — light work e.g. desk work, or driving a car or truck									
Sitting — moderate work e.g. working heavy levers or riding a mower or forklift truck									
Standing — light work e.g. lab technician work or working at a shop counter									
Standing — light/moderate work e.g. light welding or stocking shelves									
Standing — moderate work e.g. fast rate assembly line work or lifting up to 50 lbs every 5 minutes for a few seconds at a time									
Standing — moderate/heavy work e.g. masonry/painting or lifting more than 50 lbs every 5 minutes for a few seconds at a time									
Walking at work — carrying nothing heavier than a briefcase e.g. moving about a shop									
Walking — carrying something heavy									
Moving, pushing heavy objects objects weighing over 75lbs									

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If you do any other activities which we have not included, please list them in the space below

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STAIR OR STEP CLIMBING AT WORK

*Please put a tick (✓) on **every** line*

	AVERAGE OVER THE PAST YEAR		
	Job 1	**Job 2**	**Job 3**
Number of times you climbed up a flight of stairs (10 steps) each day			
Number of times you climbed up a ladder each day			

KNEELING AND SQUATTING AT WORK

In an average working day did you

Kneel for more than one hour in total?	Yes ☐	No ☐	Don't know ☐
Squat for more than one hour in total?	Yes ☐	No ☐	Don't know ☐
Get up from kneeling or squatting more than 30 times?	Yes ☐	No ☐	Don't know ☐

TRAVEL TO AND FROM WORK

JOB 1

Please complete EVERY line

Roughly how many miles is it from home to Job 1?	
How many times a week did you travel from home to Job 1?	

How do you normally travel to Job 1?	Always	Usually	Occasionally	Never or rarely
By car				
By works or public transport				
By bicycle				
Walking				

JOB 2 *(if appropriate)*

Please complete EVERY line

Roughly how many miles is it from home to Job 2?	
How many times a week did you travel from home to Job 2?	

How do you normally travel to Job 2?	Always	Usually	Occasionally	Never or rarely
By car				
By works or public transport				
By bicycle				
Walking				

JOB 3 *(if appropriate)* **Please complete EVERY line**

Roughly how many miles is it from home to Job 3?	
How many times a week did you travel from home to Job 3?	

How do you normally travel to Job 3?	Always	Usually	Occasionally	Never or rarely
By car				
By works or public transport				
By bicycle				
Walking				

Section C RECREATION

The following questions ask about how you spend your leisure time.

Please indicate how often you did each activity on average over the past year.

For activities that are seasonal, e.g. cricket or mowing the lawn, please put the average frequency during the season when you did the activity.

Please indicate the average length of time that you spend doing the activity on each occasion.

EXAMPLE

You would complete the table below:

If you had mowed the lawn every fortnight in the grass cutting season and took 1 hour and 10 minutes on each occasion.

If you went walking for pleasure for 40 minutes once a week.

Please give an answer for the AVERAGE TIME you spent on each activity and the NUMBER OF TIMES you did that activity in the past year

	Average Time per episode		Number of times you did the activity in the past year							
	Hours	Mins	None	Less than once a month	Once a month	2 to 3 times a month	Once a week	2 to 3 times a week	4 to 5 times a week	Every day
Mowing the lawn	1	10				✓				
Walking for pleasure		40					✓			

EXAMPLE

Now please complete the table on pages 10 and 11

Please give an answer for the AVERAGE TIME you spent on each activity and the NUMBER OF TIMES you did that activity in the past year

	Average Time per episode		Number of times you did the activity in the past year							
	Hours	Mins	None	Less than once a month	Once a month	2 to 3 times a month	Once a week	2 to 3 times a week	4 to 5 times a week	Every day
Swimming — competitive or laps										
Swimming — leisurely not laps										
Backpacking or mountain climbing										
Walking for pleasure — you should not include walking as a means of transportation as this was included in Sections A & B										
Racing or rough terrain cycling										
Cycling for pleasure — you should not include cycling as a means of transportation										
Mowing the lawn — during the grass cutting season										
Watering the lawn or garden in the summer										
Digging, shovelling or chopping wood										
Weeding, pruning										
DIY e.g. carpentry, home or car maintenance										
High impact aerobics, step aerobics										
Other types of aerobics										
Exercises with weights										
Conditioning exercises e.g. using an exercise bike or rowing machine										

Please continue on the next page

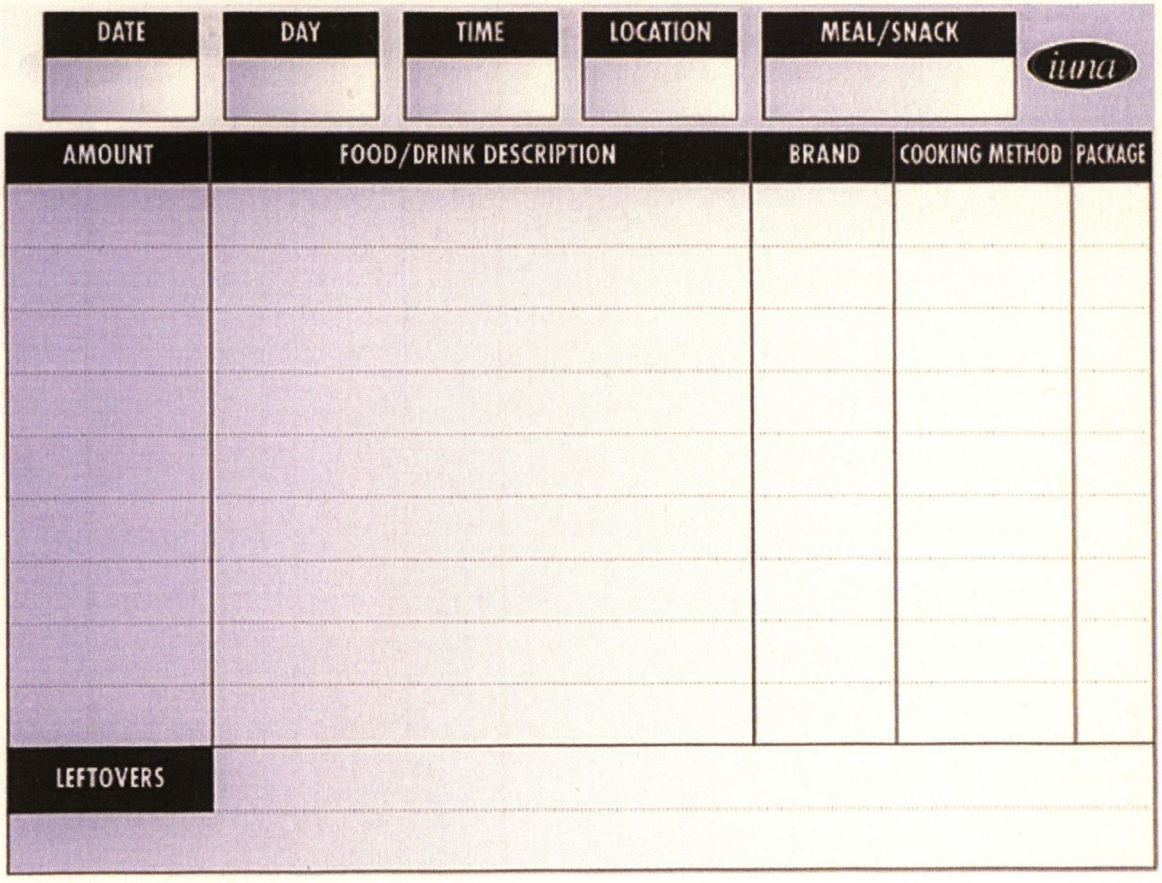
	Average Time per episode		Number of times you did the activity in the past year							
	Hours	Mins	None	Less than once a month	Once a month	2 to 3 times a month	Once a week	2 to 3 times a week	4 to 5 times a week	Every day
Floor exercises e.g. stretching, bending, keep fit										
Dancing e.g. ballroom, disco										
Competitive running										
Jogging										
Bowling — indoor, lawn or 10 pin										
Tennis or badminton										
Squash										
Table tennis										
Golf										
Football, rugby or hockey (during the season)										
Cricket (during the season)										
Rowing										
Netball, volleyball basketball										
Fishing										
Horse-riding										
Snooker, billiards, darts										
Musical instrument playing, singing										
Ice-skating										
Sailing, wind-surfing, boating										
Winter sports e.g. skiing										
Martial arts, boxing wrestling										
Other exercises (specify)										

You have finished the questionnaire — *Thank you*

Appendix II

Food Diary

Sample page from the food diary used in the North/South Ireland Food Consumption Survey.



DATE	DAY	TIME	LOCATION	MEAL/SNACK	iuna

AMOUNT	FOOD/DRINK DESCRIPTION	BRAND	COOKING METHOD	PACKAGE
LEFTOVERS				