Scientific Advisory Committee on Nutrition

SACN Energy Requirements Working Group Draft Report

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1 Summary

To be written once the report has been finalised.

2 Introduction

Background

1. The Dietary Reference Values (DRV) for food energy provide criteria against which to judge the adequacy of the food energy intake for the majority of the population and for population subgroups[1]. These DRVs apply to groups of healthy people and are not appropriate for the definition of individual requirements. The DRVs support the maintenance of health in a population and are derived with the assumption that the requirements for all other nutrients are met. The DRVs for food energy are defined as the Estimated Average Requirement (EAR). They are used for various purposes which include informing the provision of food in clinical and institutional settings.

2. The National Diet and Nutrition Survey (NDNS) series shows average reported energy intakes to be consistently below the level indicated by the EAR for food energy[2-11]. The NDNS and other surveys of the UK population show that the number of people classified as overweight or obese is increasing. These data indicate that average habitual energy intake does in fact exceed energy needs.

3. One explanation for this apparent paradox is that reported intakes of food energy assessed in the NDNS are lower than intakes actually consumed. Under-reporting of food intake in most dietary surveys is now widely recognised[12] and many individuals report food energy intakes which, if correct would induce weight loss.

4. Another possible explanation for the apparent paradox is that average energy expenditure is, in fact, lower than that anticipated in the EAR for food energy used to compare measured energy intakes in the UK.

5. The EARs for food energy published by the Committee on Medical Aspects of Food and Nutrition Policy (COMA) (1991)[1] were based on limited available evidence. More recent observations on the energy expenditure in a wide variety of population groups together with the publication of FAO/WHO/UNU updated recommendations for energy intake from the expert consultation on Human Energy Requirements[13] indicate that the average total energy expenditure of the population is highly unlikely to be below that assumed in COMA's EAR.

6. Even relatively sedentary populations are now thought to exhibit higher rates of energy expenditure than previously expected[14;15]. Consequently the revised reference values published by FAO/WHO/UNU in 2004 differ from those set by COMA in 1991, being generally higher. It is timely to review the evidence and the Food Standards Agency and the Department of Health therefore requested the re-evaluation of the DRVs for food energy by the Scientific Advisory Committee on Nutrition (SACN).

Terms of reference

The Terms of Reference for the Energy Requirements Working Group are to:

- Review and agree on the interpretation of the methods, definitions and assumptions used by Committee on Medical Aspects of Food Policy (COMA)[1] and FAO/WHO/UNU expert consultation on Human Energy Requirements[13] to agree energy requirements.

- Agree a framework by which to arrive at energy requirements for the UK population and its subgroups.

- Agree population based Dietary Reference Values for energy, and provide recommendations taking into account age, body size, levels of activity, gender and physiological state (i.e. growth, pregnancy and lactation).

- Consider the implications of these recommendations on the requirements for other nutrients.

Report methodology

7. The report considers: UK dietary intakes of energy; UK physical activity and energy expenditure levels; UK population energy requirements; the effect of diet on the risk of weight gain; and the effect of physical activity on the risk of weight gain. Evidence was identified and considered using the SACN Framework for the Evaluation of Evidence[16](as discussed in Chapter 3).

Definition of energy requirement

8. The energy requirement of an individual has been defined by FAO/WHO/UNU as 'the amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity consistent with long-term good health. This includes the energy needed for the optimal growth and development of children, for the deposition of tissues during pregnancy, and for the production of milk during lactation consistent with the good health of mother and child'[13].

9. Energy requirements defined in this way are determined from measurements of energy expenditure on healthy, well-nourished individuals and are affected by age, gender, body size and composition, pregnancy, lactation and physical activity. These characteristics are used to describe population groups for whom DRVs are defined.

Variability

10. Measurements of energy needs that are used to predict DRVs for a particular population group will, for a number of reasons, exhibit variability. Consequently, there will be a distribution of energy reference values for each population group and the level set for the

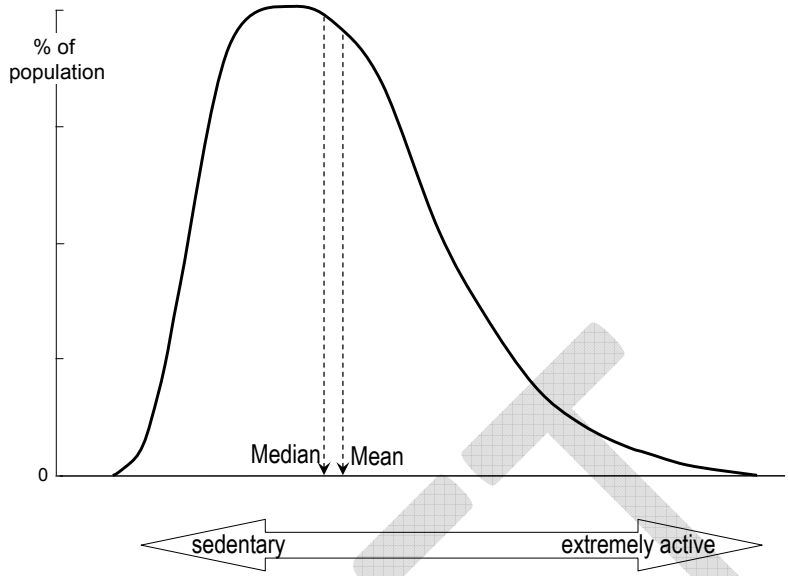
DRV should take this into account.

11. For most nutrients the DRV is identified from the upper bound of the reference ranges i.e. two notional standard deviations above the average reference value[1]. However for dietary energy the DRV is defined differently i.e. it is equal to the average reference value (Estimated Average Requirement, EAR). For individuals within a population group, an energy intake equal to the mean plus two notional standard deviations would probably result in excess energy intakes for all except a few percent of individuals. Energy intakes that consistently exceed requirements lead to weight gain and obesity, in the long term. An intake equal to the average reference value for a population group on the other hand is, in theory, associated with similar probabilities (50%) of excessive and insufficient energy intakes for any individual within the population. On this basis, the DRV for dietary energy has usually been defined as the mean energy requirement of those who constitute the defined group.

12. Appetite regulation allows humans in good health to match broadly their energy intake to their requirements so the chances of energy deficiency are low unless food supply is limited. However, this mechanism is not always sufficiently sensitive to prevent small excesses leading to inappropriate weight gain in the long term.

13. Due to the increasing trend towards sedentary lifestyles in both occupational and leisure time, especially within the adult population, and increasingly so in younger populations, the energy reference values are unlikely to be normally distributed. Measurements of energy expenditure within adult populations (see Appendix 1 for a description of the methodology for measuring energy expenditure and the uncertainties that exist in its application and interpretation), indicate that the overall distribution is positively skewed. For the high proportion of individuals who are relatively inactive, energy expenditure and intakes that maintain energy balance will cluster at the lower end of the range. A small proportion will be more active, with a few individuals exhibiting the highest rates of expenditure that are sustainable. A schematic of the probable distribution within the adult population is shown in Figure 1. Statistical considerations, therefore, dictate that the appropriate descriptor of the midpoint of the distribution is the median which is likely to be somewhat lower than the mean.

Figure 1. Schematic of the likely distribution of energy expenditure (expressed as a multiple of BMR) and hence reference intakes within the adult population



14. A second difficulty in estimating energy reference values is evidence suggesting that, at least within the adult population, energy expenditure varies between individuals with similar lifestyles over a wider range than would be expected. This is particularly important because in the past, attempts have been made to define energy reference values in terms of specific physical activity levels for specific lifestyle population groups. Consequently, with the probable exception of those at the extremes of the activity range, lifestyle predictions of energy expenditure and the resultant energy reference values cannot be made with the certainty assumed in previous reports such as COMA (1991)[1] (see Appendix 2 for a detailed consideration).

Approaches used to set energy reference values

15. There are two basic approaches to setting energy reference values:

    1) Measurement of energy intake (EI) of healthy reference populations provides, in theory, a direct estimate of the energy requirement. However it has not proved possible to make such measurements with sufficient accuracy for them to be useful. In addition, EI is not a physiological measure of the energy requirement. This is because it is not adequately regulated through the appetite mechanism to precisely match energy expenditure (EE) and allow exact energy balance and EI can be consciously altered by the subject. Also there is no independent check on whether the measured EI does match EE and is therefore appropriate for the subject's need. The breast-fed infant is the one possible exception to these caveats, but in practice this approach has been largely abandoned.

    2) Measurement or prediction of energy expenditure provides a physiological measure of the energy requirement at energy balance. This is because for energy balance, EI must

match EE, and while EI is to some extent regulated to match EE there is little evidence that EE is regulated to match EI. Thus the energy requirement can be specifically predicted as the rate of energy expenditure plus any additional needs for growth, pregnancy and lactation. EE can be accurately measured by a variety of calorimetric methods, and with $^{2}H_{2}O^{18}$, doubly labelled water (DLW) in free living subjects over periods of weeks (see paragraph 61 and Appendix 1 for more detail). Knowledge of the rates of EE associated with specific short term activities such as climbing stairs, allow EE over 24h to be predicted from a timed record of individual activities. The DLW method has proved to be the most useful approach and measurements obtained by this method which are judged to be representative of the current UK population form the basis of the estimates of energy reference values in this report.

Components of energy expenditure

16. The total energy expenditure (TEE) of an individual can be divided into a number of discrete components, which can be determined separately. These are the daily energy used to maintain *basal metabolic rate* (BMR; metabolism at rest), energy expended in physical activity, and other components such as thermogenesis deriving mainly from food intake, and growth.

Basal and resting metabolism

17. The basal metabolic rate (BMR) is a measure of an individual's metabolism in a basal state: i.e. while awake and resting. This is a standardised metabolic state corresponding to the situation at thermoneutrality and when food and physical activity have minimal influence on metabolism. It represents the metabolic activity of cells and tissues and the physiological functions essential for life. BMR and resting metabolic rate (RMR) are often used interchangeably, but if RMR is not measured at the standardised metabolic state, it can include additional metabolic activity (e.g. thermic effect of food and excess post-exercise oxygen consumption, see below), and would therefore be greater than the BMR. Because the BMR includes a small component associated with arousal, it is slightly higher than the sleeping metabolic rate. For most people BMR is the largest component of energy expenditure and requirements, ranging from 40 to 70% depending on age and lifestyle.

Physical activity

18. Physical activity is a complex and multi-dimensional behaviour taking place in a variety of domains: in transportation, domestic life, occupation and recreation[17]. The dimensions of a specific physical activity are defined as its volume, frequency, intensity, time and type.

19. 'Physical activity', 'exercise', and 'physical fitness' are terms that describe different concepts. Physical activity is defined as any bodily movement produced by the contraction of skeletal muscles resulting in energy expenditure[18]. Exercise is a subset of physical activity that is planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness and/or health.

Physical fitness is a set of attributes that are health- and/or performance-related. The degree to which people have these attributes can be measured with specific tests[18].

20. Physical activity-related energy expenditure (PAEE) is quantitatively the most variable component of TEE. The energy expended depends on the type and duration of activities, but for most individuals, the amounts which can be sustained account for 25-50% of energy requirements. In extreme situations during heavy, sustained physical activity, PAEE can account for up to 75% of energy requirements[19], but such levels of activity are highly unusual and not sustainable. Due to differences in body size, skill and training there is a large inter-individual variation in the energy expended for any given activity.

21. The energy costs of different physical activities can be expressed as multiples of BMR to account for differences in body size, i.e. the physical activity ratio (PAR). Such energy costs can also be expressed as multiples of the metabolic energy equivalent (MET): the oxygen consumption of energy expenditure measured at supine rest (defined as 3.5 ml oxygen consumption/kg body weight/minute). 1 MET is similar to the BMR, but its precise relationship will vary as a function of body weight, age and gender, which each influence BMR per kg body weight[20]. The physical activity level (PAL) used in TEE calculations is discussed in paragraphs 27-34.

22. The role of physical activity in raising TEE depends on the intensity and duration of the activity undertaken and whether this affects the degree to which other physical activities are performed, i.e. an increase in one component in PAEE may be balanced by a compensatory decrease in another. In addition, many studies of human subjects indicate a short-term elevation in RMR following single exercise events (generally termed the excess post-exercise oxygen consumption; EPOC). This EPOC appears to have two phases, one lasting less than 2 hours and a smaller more prolonged effect lasting up to 48 hours [21]. The EPOC varies with exercise intensity and duration. The effects of long term exercise training on BMR, however, are less clear[21].

Spontaneous physical activity and non-exercise activity thermogenesis

23. Spontaneous physical activity (SPA) is a term used to describe all body movements associated with activities of daily living, change of posture and 'fidgeting'[22]. SPA accounts for a between individual variation in energy expenditure of ± 15% and has been shown to be highly reproducible within individuals, a familial trait and to significantly correlate with free-living TEE measured by DLW[23;24;24]. SPA displays an inverse relationship with future weight gain[23] and it has therefore been described as a putative obesity subphenotype[24]. It has been argued that because SPA has only been quantified within a calorimeter it cannot be regarded as a component of free living TEE in its own right in comparison to BMR and the thermic effect of food (TEF, see paragraph 35). It is described as "*a useful paradigm to quantify an individual's propensity to locomotion under standardized conditions*" [24].

24. Non-exercise activity thermogenesis (NEAT) is another term used to describe the additional energy expenditure attributable to spontaneous physical activities other than volitional exercise, during everyday activities[25]. Like SPA, NEAT has been implicated in energy balance regulation following observations in overfeeding studies that subjects exhibiting high levels of NEAT[25] displayed a resistance to fat gain. More recently

however the term NEAT has been applied by the same author to all ambulatory activity, apart from specific sports, including relatively high level exertion activities such as dancing[26], and with walking identified as the predominant component. In this context, NEAT ceases to be an appropriate term since easily identifiable exercises have been included.

25. Although both SPA and NEAT may be used to describe "fidgeting" in popular parlance, they are each likely to involve a much wider range of behaviours influencing energy expenditure. Thus SPA as an "individual's propensity to locomotion[24]" is likely to exhibit itself in terms of the involuntary choices between low and high expenditure activities which are a continuous feature of daily living (for example, standing or walking up escalators, using lifts or stairs). In this report the term SPA, rather than NEAT, will be used in the wider sense to represent spontaneous physical activity which can occur within any domain. As such, SPA is potentially quantifiable as the technology for measuring movement and activity improves.

26. SPA, with its potential magnitude, and large between-individual but small within-individual variation, represents a behavioural phenotype which is likely to significantly influence individual energy expenditure independently of lifestyle categories.

The physical activity level (PAL)

27. A detailed discussion of PAL is provided in Appendix 2, an overview is given here. Twenty four hour TEE is a complex function of weight, age, gender, lifestyle and behavioural phenotype, but can be simplified and expressed as the ratio of TEE to BMR. This is defined as the physical activity level, PAL, or the physical activity index, PAI. PAL is therefore an index of 24h TEE adjusted for BMR, and is theoretically independent of those factors influencing BMR (weight, age and gender), at least as a first approximation. In the present context, PAL is important because it can be used to predict TEE and hence energy reference values as PAL x BMR.

28. PAL values are best estimated from direct measures of 24h TEE and BMR. Such measurements in free-living populations have indicated that PAL can range from <1.3 in immobile subjects to between 3-4.7 for limited periods of time in soldiers on field exercises and elite endurance athletes or Antarctic explorers[15;27]. Within the general population, however, the overall range of PAL values for individuals in energy balance, leading sustainable lifestyles, is between 1.38 for the most sedentary to 2.5 for the most active[14;28-32]. A change in lifestyle will change an individual's PAL value by reasonably predictable amounts. For example, an additional 30 minutes of moderate intensity activity five times a week, as currently recommended for adults in the UK, will raise PAL by about 0.15 units (see Appendix 2 for details).

29. In previous reports, including COMA (1991)[1] the duration and energy cost of individual activities (as PAR or MET values) has been summed to provide factorial estimates of PAL[1;13,20;33] . A comprehensive summary of all published PAR values for a wide range of different physical activities for adults was recently compiled[34].

30. The factorial prediction of PAL assumes that overall energy expenditure within the general population can be predicted using information derived from activity diaries or lifestyle questionnaires. However, there is little evidence that this can be done with sufficient accuracy for several reasons.

31. Firstly, for most lists of activities used to identify lifestyle categories, individual activities are only defined in general qualitative terms. Consequently, there can be large inter-individual variations in the energy expended for each activity. In part this is due to variation in activity intensity resulting from variation in fitness measurable as VO_{max}[35]. Also, such listed energy costs may or may not account for TEF or EPOC.

32. Secondly, factorial estimates generally assume that time not allocated to activities is occupied by basal energy expenditure and take no account of spontaneous physical activity[28]. Indeed, the potential for some spontaneous physical activity throughout the range of defined activities adds to the uncertainty that their energy costs can be predicted.

33. The extent to which factorial estimates of PAL will be in error has not previously been systematically evaluated. However, an examination of this question in Appendix 1, in terms of the DLW-derived TEE literature, identifies considerable evidence that classification of individual lifestyles is a poor predictor of PAL.

34. In this report, factorial predictions of PAL values for specific lifestyle categories have not been attempted due to the likely error in estimating actual TEE from listed PAR values of activities and the phenomenon of behavioural phenotypes with very variable rates of energy expenditure. Instead, values for PAL for children, adolescents and adults have been identified from an analysis of the available TEE literature judged to be appropriate for the UK population (see paragraphs 74 and 128-135).

Other components of energy expenditure

Thermic effect of food

35. The thermic effect of food (TEF) or heat increment of feeding can be attributed to the metabolic processes associated with ingestion, digestion and absorption of food, and the intermediary metabolism and deposition of nutrients. TEF varies mainly according to the amount and composition of dietary macronutrients (see paragraphs 48-51) and is usually assumed to account for 10% of energy intake[36]. This means that for any individual the energy used in TEF varies in absolute terms according to overall rates of energy intake, and will usually be greater than 10% of BMR over a 24 hour period in individuals eating a mixed diet.

Growth

36. Physical growth involves an increase in both the size and complexity of body structure, occurring under genetic and endocrine regulation in the presence of adequate nutrient supply. During growth, organs and tissues do not grow at a uniform rate[37], e.g. in the full-term newborn the brain represents about 12% of body weight, but in the adult is about 2%. Energy is deposited into new tissues and expended during the synthesis of growing tissues. The energy required for growth is highest in the first 3 months of life when it accounts for about 35% of energy requirements, by 12 months of age this has fallen to about 3%[38]. The energy cost of growth remains low from one year of age to mid-adolescence, then increases slightly during the adolescent growth spurt; by the late teens the amount becomes very small[39].

37. Changes in relative organ size influence both energy and protein metabolism. The rate of

protein synthesis per unit of body mass proceeds at a high rate in the neonate and declines throughout infancy. High protein turnover contributes to the relatively high energy requirement of the newborn. Gender differences in body composition become more apparent after puberty. The developmental aspects of body composition and whole body metabolism affect the energy cost of growth[40;41].

Pregnancy and lactation

38. During pregnancy, there are energy requirements for placental and fetal growth and for the growth of maternal tissues, e.g. uterus, breast and adipose tissue triglycerides. In addition to these growth costs, there are the increased energy costs from changes in maternal metabolism and a larger tissue mass, along with an increased energy cost of movement, particularly for weight bearing activities after 25 weeks[42].

39. During lactation, energy is lost as secreted milk and expended in producing the milk. Fat reserves that accumulate during pregnancy provide a variable proportion of this requirement[43].

40. The TEE during growth, pregnancy and lactation does not include the energy content of any tissue laid down at this time or milk produced; these are estimated from analysis of tissue deposition and milk secretion. The TEE, however, does include the energy required for new tissue synthesis or milk production.

Food energy

41. Ingested food contains chemical energy in the form of carbohydrate, fat and protein, and alcohol. The maximum amount of food energy available from a food can be determined by measuring the heat released after its complete combustion to carbon dioxide and water. This is the gross energy (GE), but not all GE is available for human metabolism.

42. Available energy is defined as metabolizable energy (ME) and the ME value of a food or diet can be measured as the difference between energy intake and losses in faeces and urine (and a small amount in sweat). Energy losses in faeces mainly represent incomplete digestion while energy losses in urine and sweat are primarily due to the urea content which represents the incomplete catabolism of protein.

43. The ME content is the value quoted as the energy content of foods on food labels and in the UK food composition tables[44]. The ME content of a given food can be calculated from the amounts of protein, fat, carbohydrate and alcohol in the food (determined by chemical analysis) using energy conversion factors (see Table 1). These conversion factors are estimates of the energy content of each macronutrient and alcohol and have been rounded for practical purposes. Alternatively UK food composition tables, which are based on analytical data, can be used to estimate the ME content of a wide variety of commonly consumed foods.

44. Some ME is utilized as a result of the thermic effect of food[45] (see above). The extent of this varies with the type of food ingested, but specific amounts are associated with amino acid metabolism, alcohol metabolism and the microbial fermentation of otherwise

unavailable carbohydrate. Energy lost via TEF may be subtracted from ME, resulting in an expression of the capacity of food energy to fuel metabolic work or for conversion to stored energy. This is termed the net metabolizable energy (NME)[46]. While the ME and NME values are the same or similar for available carbohydrate and fat, NME values are lower for protein, alcohol and fermentable non-starch polysaccharides.

45. The body is able to capture some of the chemical energy from food through cellular metabolism, resulting in the generation of an intermediary chemical form, adenosine triphosphate (ATP). ATP acts as an energy source for cellular processes mainly through phosphorylation of proteins and other intermediates and is regenerated from ADP using the energy in food. Cells require chemical energy for three general types of tasks: 1) to drive metabolic reactions that would not occur automatically; 2) for the transport of substances across cell membranes especially against a concentration gradient; and 3) for mechanical work, e.g. muscle contraction. Energy is also released as heat both in the formation of ATP and during its use in these metabolic processes, and this maintains body temperature. Food energy can also be directly converted to heat if the oxidation pathway is uncoupled from the ATP-producing process.

46. FAO/WHO/UNU reviewed the case for the use of NME in place of ME values[46]. While it was recognised that NME represents the biological ATP-generating potential of foods, it was recommended that, for the present, the ME system should be retained. The Working Group endorses the FAO/WHO/UNU recommendation, that the ME system should continue to be used and, at this time, the NME system should not be adopted.

Energy yields from substrates

47. The unit of energy in the International System of Units (SI) is the joule (J) and is the energy expended when an object is moved one metre by a force of one newton in the direction in which the force is applied. A newton is the SI unit of force and one newton will accelerate a mass of one kilogram at the rate of one metre per second. Nutrition scientists, physiologists and food scientists are concerned with large amounts of energy and the convenient units are the kilojoule (kJ = 10^3 J) and the megajoule (MJ = 10^6 J). The thermochemical calorie is equivalent to 4.184 J (1 kcal = 4.184 kJ).

Fat

48. The amount of energy yielded from fat in food varies slightly with the type of food, mainly according to the chain length and degree of saturation of constituent fatty acids in dietary triglycerides. It is generally assumed that the digestibility of all dietary fat is the same (≅95%). In practice because dietary fat incorporates a mixture of different fatty acids these differences are ignored and the metabolizable energy content of dietary fat (the general Atwater factor) is assumed to be 37kJ (9.0 kcal/g), i.e. equal to the digestible energy content at 95% of gross energy.

Carbohydrate

49. The amount of energy yielded from different carbohydrates in food varies according to the molecular form. For the different forms of carbohydrate i.e. glucose, disaccharides and starch, the actual available energy content per unit weight is15kJ (3.6 kcal/g), 16kJ (3.8 kcal/g) and 17kJ (4.0 kcal/g) respectively. FAO/WHO/UNU, however, has

recommended that when carbohydrate is expressed as monosaccharide equivalents, a conversion factor of 16 kJ/g (3.8 kcal/g) should be used, and when determined by direct analysis, it should be expressed as the weight of the carbohydrate with a conversion factor of 17 kJ/g (4.0 kcal/g); the latter value being an estimated average of the different forms of carbohydrate in food.

Table 1. Metabolizable energy (ME) conversion factors [44].

	ME factors	
	kJ/g	kcal/g
Fat	37	9.0
Available carbohydrate expressed as monosaccharide	16	3.8
Fermentable non-starch polysaccharides	8	1.9
Protein	17	4.0
Alcohol	29	6.9

50. Other carbohydrates may also provide energy. Fermentation of non-starch polysaccharides in the colon results in the formation of short-chain fatty acids, some of which are absorbed into the blood stream and are used as energy. A conversion factor of 8 kJ/g (1.9 kcal/g) has been suggested[46], as have conversion factors for organic acids (13 kJ/g; 3.1 kcal/g), and polyols (10 kJ/g; 2.4 kcal/g). The UK food composition table energy values only include carbohydrate expressed as monosaccharide[44]. The COMA DRV report[1] noted that diets rich in non-starch polysaccharides were associated with a lower apparent digestibility of fat and protein and that this apparent loss in available energy was similar to the net gain in energy intake from certain non-starch polysaccharides.

Protein

51. The amount of energy yielded from protein in food can vary according to both the quality and the digestibility of the protein. These differences can mean that the energy yield from some highly digestible animal proteins like egg may be 40% greater than for some less digestible plant proteins. Also, as discussed above in relation to the net metabolizable energy, the immediate metabolic fate of amino acids absorbed into the body includes deamination and other reactions which contribute to the thermic effect of feeding. However this energy loss is usually ignored. The metabolizable energy content of dietary protein (the general Atwater factor) is assumed to be 17kJ (4.0 kcal/g), a value which is slightly lower than the actual value for most animal proteins and higher than that for most plant proteins. Because dietary protein usually represents a mixture of several animal and plant protein sources the average energy yield will usually be close to the assumed ME content.

Alcohol

52. Alcohol oxidation starts rapidly after absorption, and alcohol is eventually completely eliminated by oxidation[47;48]. Consumption of alcohol can modestly activate the hepatic *de novo* lipogenesis pathway, but acetate produced in the liver (by alcohol dehydrogenase) and released into plasma inhibits adipose tissue lipolysis, alters tissue fuel selection, and represents the major quantitative fate of ingested ethanol[49]. The results from studies on the magnitude of the thermic effect of food (see paragraph 35) after

alcohol consumption vary, with reported values ranging between 9% and 28%[47;50].

Energy balance and storage

53. Energy balance is achieved when metabolizable energy intake is equal to total energy expenditure, plus the energy cost of growth in childhood and pregnancy or the energy cost of milk production during lactation. A positive energy imbalance occurs when energy intakes are in excess of these requirements while negative energy imbalance occurs when they are not met by intake.

54. Energy intake needs to exceed total energy expenditure during growth, pregnancy and lactation when new tissues are being laid down or milk produced. In other circumstances, the energy is stored. Triglycerides within adipose tissue act as the body's major energy store. Some energy is also stored in liver and skeletal muscle as glycogen. The amount of energy stored in the adipose tissue of a healthy adult of normal weight is equivalent to approximately one month's energy requirements[51].

55. Short-term, day to day energy imbalances are accommodated by the deposition and mobilisation of glycogen and fat. Positive and negative energy imbalances occur in the short term in free living individuals, so, in terms of weight regulation, it is important to consider the overall energy balance over a prolonged period of time.

56. Chronic negative energy imbalance results in the utilization of stored energy from triglyceride in adipose tissue and protein in muscle and viscera since glycogen stores are limited. Chronic positive energy imbalances are mostly accommodated by the deposition of adipose tissue triglycerides, together with a small but fixed ratio of lean tissue[51]. Thus an individual in chronic positive energy imbalance stores excess food energy mainly as triglyceride and to a lesser extent protein. Muscle and liver glycogen stores are modest and have a limited capacity; whereas, the capacity of the body to store triglycerides in adipose tissue is substantial.

Methodologies for estimating energy reference values

57. As previously discussed (paragraph 15), reported energy intakes consistently under-report and are systematically biased towards underestimation. Consequently, estimation of energy reference values from reported intake has been discarded in favour of approaches measuring energy expenditure.

58. Measurement or prediction of total energy expenditure (TEE) provides a physiological measure of the energy requirement at energy balance. For infants, children and pregnant and lactating women there are additional energy needs. These are energy deposited in new tissue, in the products of conception and in breast milk secreted by the mother, and the energy expended in the synthesis of these components. The latter costs will be included in TEE measured in these population groups but provision must be made for energy deposition costs which are added to TEE to provide overall energy requirements.

Measurement of total energy expenditure

59. There are several approaches used to measure total energy expenditure. Short term

measurements under highly defined conditions can be made by calorimetry. The most accurate is direct calorimetry which measures the rate of heat loss from the subject to the calorimeter. Indirect calorimetry, the most commonly used approach, measures oxygen consumption and/or carbon dioxide production from which total energy expenditure is calculated using standard formulae such as the Weir equation.

60. The components of TEE (e.g. BMR, PAEE) can be measured separately using direct and indirect calorimetry. TEE can also be measured with large walk-in calorimeters, although the necessary confinement of subjects limits this to short periods, most often 24 hours. The information provided by these approaches is accurate and has provided the energy costs of different physical activities (as discussed in paragraph 21 and 22) and minimal daily rates of TEE. Free living activities cannot usually be measured by these techniques. Some non-calorimetric techniques can be used to predict free living TEE by extrapolation from physiological measures, the best example being heart rate monitoring[52]. These need first to be calibrated against direct or indirect calorimetry before TEE can be calculated

61. The doubly labelled water (DLW) stable isotope technique is generally recognised as the most accurate measure of free-living TEE currently available and is discussed in detail in Appendix 1. This approach enables TEE to be measured in free-living subjects over a period of several days to several weeks; other non-calorimetric methods, e.g. heart rate monitoring, provide less accurate measures[52]. The DLW technique in a sense applies the principles of indirect calorimetry in that it determines the rate of carbon dioxide production, which can be used to calculate TEE. An estimation is made of the energy equivalent of carbon dioxide calculated on the basis of the relative contribution of the macronutrients to carbon dioxide production (food quotient, FQ; usually assessed from food intake measures). Whilst the DLW method is the best available, it relies on a series of assumptions which inevitably lead to errors and undermine the accuracy of the predicted TEE values. There are also concerns regarding recruitment bias since people who are willing to participate in DLW studies may not be representative of the population as a whole.

62. In the UK it has been noted that people agreeing to take part in the DLW studies conducted as part of the NDNS tend to be more active than those who do not, despite the random recruitment protocol. It is unclear whether this phenomenon also occurs in other DLW studies, however, if this is the case, the derived TEE values and hence energy reference values may be overestimated.

Predicting BMR

63. There are a variety of prediction equations described in the literature and different authors identify different equations in their published work especially in the US and Europe. Within the UK COMA (1991) and for FAO/WHO/UNU reports, the Schofield equations have primarily been used[53-55]. These are a series of predictive equations for BMR based on body weight, age and gender, the latter two factors being the main determinants of body composition in terms of the proportion of the fat free mass. They are derived from an analysis of a compilation of calorimetric measures of BMR values and anthropometric data. These predictive equations, slightly modified, form the basis for FAO/WHO/UNU energy requirements for adults[13] and modified versions were used for the previous UK EAR for energy in children aged 3-18 years and adults[1].

64. The dataset upon which the Schofield predictive equations for BMR were based was mostly compiled from results in West European and North American subjects, with almost half being Italian subjects in whom BMR was estimated using a closed circuit method[1] in the 1930s and 1940s[57]. Questions have been raised about the applicability of these equations to all population groups and an alternative more comprehensive database has been assembled and analysed from which a new set of equations have subsequently been derived, i.e. the Henry equations[57] (see Appendix 3). Although the Schofield and Henry prediction equations result in only small differences for children or adults, a recent assessment of the validity of different predictive equations for BMR in adults found the Henry prediction equations to be the most accurate[58]. In this report the BMR prediction equations published by Henry[57] are therefore recommended. A more detailed discussion of the reasons supporting this decision is provided in Appendix 3.

Calculation of energy requirements

65. The factorial approach to estimating energy requirements originally proposed by FAO/WHO/UNU in 1985, adopted by COMA 1991 and by the most recent FAO/WHO/UNU[13] report for calculating energy requirements of adults, involves the prediction of TEE as PAL x BMR. As described above, BMR is predicted from anthropometric measures. These reports were based on the assumption that values for PAL can be estimated from time-allocated lists of daily activities expressed as PAR values (see paragraph 21). With information about PAL values for specific lifestyles and types of daily activities, appropriate PAL values can then be assigned to particular population groups. Given the reservations expressed about predicting PAL by factorial estimates (see paragraphs 30-34 and Appendix 2), for this report, only *measured* values of TEE will form the basis of determining energy reference values. In this case there are two potential analytical approaches.

66. The first approach is to use measured TEE directly to derive regression equations which describe how TEE varies as a function of anthropometric variables (such as weight and height) for defined population groups. The regression equation can then be used to predict TEE and resulting energy reference values for any group on the basis of their anthropometric variables.

67. The second approach involves dividing measured TEE by BMR (measured or predicted) to extract PAL values. This means that the reference populations studied by DLW are described primarily by PAL values. These PAL values are then used in a factorial prediction of TEE as PAL x BMR.

[1] The methods available to measure BMR may be divided into two types; closed and open circuit methods. In the closed circuit indirect calorimetry method, the subject breathes in and out of a closed system, commonly a spirometer, which is sealed to room air. Oxygen, or a mixture of oxygen and nitrogen, is supplied to the spirometer at the rate at which it is consumed. Thus the rate at which oxygen is delivered is the same as oxygen consumption. Heat production may be estimated from oxygen consumption alone (Weir, 1949), in which case the carbon dioxide produced by the subject is absorbed, for example by soda lime within the closed breathing circuit. Alternatively, weight gain of the carbon dioxide absorber may be used to derive carbon dioxide production using this method. (From: Consensus in Clinical Nutrition[56])

Predicting TEE with regression equations

68. The analysis of TEE as a function of its potential predictor variables (weight, age and gender) by multiple regression techniques would seem a logical progression from the accumulation of reliably estimated measures of free-living TEE, especially by the DLW method[59]. In practice, however, a major limitation to this approach has been the inability of TEE prediction models to account for variation in PAEE, which is an important source of variation in TEE.

69. From first principles it would not be expected that variation in PAEE could be predicted from anthropometric variables. Although for many specific physical activities, mainly ambulatory locomotion, their energy cost will be a function of weight, the duration and intensity of PAEE is not physiologically related to anthropometric variables in the same way as the BMR. Thus any between-individual or between group variation in duration or intensity of PAEE will be lost in a regression model involving just anthropometric variables. The regression equation will in fact predict values for TEE which contain a PAEE component comparable to the mean value observed at any given weight or age within the dataset used to generate the regression. It might be argued that because BMR and a body weight-dependent component of PAEE account for the major part of TEE, the inclusion of a single average value for PAEE for a population group is acceptable. In practice, in previous reports in which regression models of TEE have been used to predict energy requirements, special provision has been made to take account of the likely variation in PAEE within the population group described by the regression. The way this has been done is described below (see paragraphs 70 and 71). The exceptions to this are infants within the first year of life and preschool children. In each case, in some previous reports it has been assumed that variation in TEE through variable physical activity is of minor importance and that provision for this is not required. This has enabled simple prediction equations of TEE as a function of body weight with additions for growth to be used to predict energy reference values.

70. The development of predictive equations for TEE from measured values forms the basis of the FAO/WHO/UNU[13] report on energy requirements for infants, children and adolescents (but not for adults). Datasets were developed using TEE values from DLW studies for infants and DLW and heart rate monitoring studies for children and adolescents. Mean study values weighted by the number of subjects were then used to derive the predictive regression equations. For children and adolescents the predicted TEE values were not used directly but used to predict PAL values. This was done by dividing TEE values from the regression with BMR values predicted as a function of age and weight. These calculated PAL values were assumed to represent activity levels for populations with “average” or “moderate” physical activity. Values for more (“vigorous”) or less (“light”), active lifestyles were calculated as average ± 15%. This allowed energy requirements to be calculated for the three lifestyles as PALxBMR. As indicated above (paragraph 65) FAO/WHO/UNU[13] did not use regression equations for adults but adopted a factorial model of PAL x BMR.

71. The 2005 US Dietary Reference Intake (DRI) values for energy[20] for all age and gender groups are derived from prediction equations for TEE calculated by regression analysis of a DLW dataset of individual TEE values obtained, with ancillary data, directly from the

investigators of each study. However unlike the FAO/WHO/UNU report, variation in physical activity was accommodated within the regression by designating an activity constant for each individual. Thus prior to the regression, the PAL value was calculated from TEE and the BMR for each individual TEE value in the dataset. This allowed each subject to be assigned one of four physical activity constants representing a predefined PAL range (sedentary, low active, active, very active). In this way gender-specific regression equations for the prediction of TEE were identified based on age, weight, height and physical activity categories. In practice these equations differ little from prediction equations of the form BMRxPAL with four values of PAL identified for the four activity ranges.

Predicting TEE from measured PAL values

72. As detailed above, previous dietary energy reference reports have recognised the need to include a variable physical activity factor in the calculation of TEE and energy reference values. Whilst not all experts have embraced the BMR x PAL approach[59] (see Appendix 2), no satisfactory alternative has yet been identified.

73. There are two major considerations in the practical application of this approach: 1) identifying suitable PAL values appropriate for groups and populations; and 2) utilizing this information to derive energy reference values.

74. PAL values can be calculated from measurements of DLW-derived TEE largely obtained from UK populations and comparable populations in the US and other developed countries over the last 20 years. With few exceptions, published DLW studies involve small numbers of healthy subjects reported to be engaged in activities representative of the general population at that time. Data from these studies can be combined to derive best estimates of PAL values for the population on the basis of age and gender. Questions remain however regarding how representative these values are of the current UK population (see paragraph 62). An alternative is to make use of large population studies which can be assumed to be representative of the UK population. In this report a combined analysis of all published studies has been used to identify PAL values for children and adolescents. For adults, individual values from two large population-based studies of TEE measured using DLW have been used. Both the OPEN study (n=451)[60;61] and the Beltsville study (n=476)[62] recruited healthy volunteers from Washington DC and were judged to be representative of the US population on the basis of the demographic characteristics, which are also considered similar to the current UK population. A detailed consideration of the OPEN and Beltsville studies is provided in paragraph 131 and Appendix 10.

75. Suitable PAL values can be used to update and improve tables of PAL value ranges for the various ages and lifestyle groups identified in previous reports, allowing energy reference values to be calculated for such groups. However the marked between-individual variation in PAL which seems to occur independently of any predictable lifestyle makes the selection of an appropriate PAL value unreliable. The alternative approach is to evaluate the distribution of PAL values, with medians and centile ranges of PAL values identified for the population as a whole. This allows energy reference values to be framed against such distributions, in effect substituting PAL distributions for PAL

values defined in terms of lifestyle. Thus energy reference values can be defined for the average as well as for those likely to be more or less active than the average. Although this means that only three activity groups within the population are identified by PAL values, the Committee considered it unrealistic to judge PAL values more finely. However additional information on the change in PAL with specified additional activity will allow calculation of the probable additional energy intakes required to support such activities.

Factors affecting energy expenditure

76. A detailed discussion of factors affecting energy expenditure can be found in Appendix 4, a summary is given here. Physical activity is considered in Appendix 5.

Body size and composition

77. Basal and total energy expenditure are related to body size. Both height and weight are important independent determinants of energy expenditure. In general, larger people have more tissue mass than smaller people and therefore have a higher BMR. In infants, children and adolescents, there is an increase in BMR with age, due to growth and increasing tissue mass, although the changing relative organ sizes in early life complicates the relationship between body weight and BMR.

78. After adjustment for body size, inter-individual variation in BMR and RMR is mainly determined by variation in the metabolically active tissue mass of the body, termed fat-free mass (FFM; the non-fat component of body composition comprising muscle, bone, skin and organs). The fat component of the body is termed fat mass (FM) and varies considerably between individuals in terms of the absolute amount. The differences observed in energy expenditure with gender, age and ethnicity, after adjustment for body size, are mainly accounted for by differences in body composition, i.e. FFM (see Appendix 4 for further discussion).

79. In individuals with higher percentages of body fat composition, an effect on the mechanical efficiency of movement can increase the energy expenditure associated with certain types of activity. However on a population basis for adults up to a moderate level of fatness (i.e. overweight, but not obese), such influences of fatness on activity-specific energy expenditure are generally ignored[63].

80. The increasing body size of overweight and obese individuals increases both FM and FFM and the absolute BMR[64;65] although the weight specific BMR declines with increasing body fatness[64].

Genetic variation

81. While many studies have investigated the role of genetic variation on energy expenditure there have, as yet, been no clearly established relationships between specific gene variants and energy expenditure. For example, a number of studies have investigated the association between the mitochondrial uncoupling protein gene variants and energy expenditure, but results have been equivocal.

Hormones

82. Several hormones, e.g. sex hormones, thyroid hormone, adrenaline and leptin, may affect energy expenditure and have been implicated in the regulation of energy balance. Pharmacological agents, such as glucocorticoids, amphetamines and some anti-obesity drugs have all been shown to increase energy expenditure, while opiates and barbiturates can decrease it. Smoking acutely increases resting energy expenditure to a small extent (e.g. a 3.3% increase in RMR over a 3 hour measurement period[66]).

Illness

83. The effect of illness on energy expenditure is discussed in more detail in Appendix 6. In patients with a range of conditions, infective, degenerative, malignant, traumatic, congenital and others, TEE is usually normal or reduced, partly because of a reduction in body weight and fat-free mass (FFM) as a result of disease-related malnutrition or neurological causes of wasting, and partly because of reduced physical activity. The latter compensates for any increase in BMR, which is common in acute diseases. There are some exceptions, such as subgroups of patients with cystic fibrosis, anorexia nervosa, and congenital heart disease, where TEE has been reported to be increased[67].

Ambient temperature

84. Body temperature is tightly regulated in order to maintain cell function. A component of this regulation relies on variation in energy expenditure. Differences in environmental temperature affect energy expenditure and have been shown to account for about 2-5 percent of the variation in TEE. Indoor temperatures, however, are typically controlled to remain relatively constant and individuals adjust their clothing to create a relatively constant thermal microenvironment, so in reality, ambient temperature has a minimal effect on energy expenditure. A detailed consideration is given in Appendix 3.

Obesity

85. Obesity results from a long-term positive energy imbalance. Its increasing prevalence must reflect temporal lifestyle changes, since genetic susceptibility remains stable over many generations, although inter-individual differences in susceptibility to obesity may have genetic determinants (see paragraph 97)[68].

86. Body Mass Index (BMI) (kg/m²) is often used as a convenient measure of adiposity, with recognised limitations. It has been used since the 1960s to assess obesity in adults[69] and more recently in children[70;71]. While BMI is a good measure of weight independent of height, it fails to distinguish between adipose and non-adipose body mass. When used as a proxy for FM or adiposity, assumptions are made about absolute and relative body composition, which may not be valid. BMI fails to reflect body shape, and hence fat distribution, and is not strongly related to central adiposity, which is considered the most harmful to health[72].

87. In adults, underweight is defined as BMI less than 18.5 kg/m^2, overweight is defined as 25 kg/m^2 to less than 30 kg/m^2 and obesity is defined as 30 kg/m^2 or more[73]. Insufficient energy intakes are uncommon in healthy free-living individuals in the UK and do not

generally arise from insufficient food supplies, but from accompanying physical or psychological diseases. In the 2007 Health Survey for England (HSE), 1.6% of adults were classed as underweight. The 2003/5 Low Income Diet and Nutrition Survey also found the prevalence to be low in adults living in low income households (2% of both men and women)[9]. In contrast, there is a high prevalence of overweight and obesity in the population resulting from a chronic excess of dietary energy intake over energy expenditure.

88. In children, BMI measures require cautious interpretation when comparing across groups that differ in age or when predicting a specific individual's total or percent body fat[74]. Children of the same age and gender have been shown to have a two-fold range of fat mass for a given BMI value, which is also observed in those who are obese[75]. BMI normally changes during growth and this requires careful interpretation through the use of appropriate references or standards for age and sex. In the UK the "UK 1990" growth references[76] were used until 2009 for all children up to 18 years of age. From May 2009, for children aged between 0-4 years of age, new standards are being used based on the WHO Multicentre Growth Standards[77]. For the purpose of population monitoring, children with a BMI over the 85th centile for age of the reference population are categorised as overweight and those with a BMI over the 95th centile for age as obese[78]. In UK clinical practice, however, children over the 91st centile for the reference population are categorised as overweight and those over the 98th as obese[79]. Further thresholds have been proposed for the purpose of international comparison[80]; these allow estimation of the proportion of children at each age expected to exceed a BMI of 25 or 30 at the age of 18 years. The use of different definitions that are not directly comparable can lead to difficulty in interpreting different surveys or studies of childhood obesity.

89. Tables 2 and 3 show the estimated prevalence of overweight and obesity in England among children (aged 2-15 years) and adults, between 1995 to 2007 (HSE, 2009[81]) on the basis of the UK 1990 BMI growth reference[76].

90. In 2007, 31% of boys and 30% of girls were overweight or obese (see Table 2). Obesity (as defined by a BMI over the 95th centile for age) increased from 11 % and 12% in 1995 to 17 % and 16%, in boy and girls respectively. Despite the overall increase since 1995, the proportion of girls aged 2 to 15 who were obese decreased from 18% to 15% between 2005 and 2006 and was 16% in 2007. There was no significant decrease among boys over that period, with 17% classed as obese in 2006 and 2007.

91. In 2007, an estimated 24% of men and women were obese; an overall increase from 15% in 1993. 65% of men and 56% of women were overweight and obese (see Table 3). Between 1993 and 2007, the proportion of normal weight adults decreased, the proportion overweight remained similar, while the proportion obese increased. The proportion of morbidly obese adults doubled over the same time period. In a comparison of the HSE between 1993 and 2003, both BMI and central adiposity (waist circumference) increased more in the upper part of the distribution, with intermediate increases in the middle and little change at the lower end of the distribution[82]. The observed temporal gains in central adiposity were not equivalent across the BMI distribution. Thinner people were almost as thin as they were 10 years earlier, but fatter people were considerably fatter.

92. In the 2003 Scottish Health Survey[83], 65% of men and 60% of women were either overweight or obese. Men were more likely than women to be overweight (43% vs. 34%),

but women were more likely than men to be obese (26% vs. 22%), or morbidly obese (3.4% vs. 1.6%). The proportion of adults who were either overweight or obese increased significantly between 1995 and 2003, from 56% to 64% in men, and from 47% to 57% in women. The proportion that was morbidly obese more than doubled in this time. The prevalence of obesity in boys was 18% overall, ranging from 10% at age 2-4 years to a peak of 22% at age 11-12 years. The prevalence of obesity in girls was 14%, ranging from 10% aged 2-4 years to 16% aged 8-10 years. There was an increase between 1998 and 2003 in boys in the prevalence of overweight including obesity (from 29% to 35%) and of obesity (from 14% to 18%) but no change for girls.

93. In the Health Surveys for Scotland and England objective measures of the weight and height of subjects are made, but the respective Health Surveys for Wales and Northern Ireland use self-reported measures, and are, therefore, less accurate.

94. In the 2007 Welsh Health Survey[84], 62% of men were classified as overweight or obese compared with 51% of women. In men 42% were overweight and 20% obese, while in women 31% were overweight and 21% obese. In children, 36% were estimated to be overweight or obese, including 20% obese.

95. The 2005/6 Health and Social Wellbeing Survey in Northern Ireland[85] observed 64% of men and 59% of women to be either overweight or obese. In men, 39% were overweight and 25% obese, while in women 35% were overweight and 24% obese. In boys, 18% were overweight and 20% obese and in girls 16% were overweight and 15% obese.

Table 2. Overweight and obesity prevalence among children, by year, 1995 to 2007[1], in the Health Survey for England 2007

	Percentages												
	Unweighted[2]								Weighted[3]				
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
All Children													
2-15													
Overweight[4]	13.1	13.0	13.0	14.1	14.0	12.5	15.1	13.8	14.6	15.2	14.3	13.7	14.0
Obese[4]	11.5	11.9	12.6	13.4	15.1	14.3	15.0	17.0	16.6	18.8	18.3	16.0	16.5
Overweight including obese	24.5	24.9	25.6	27.5	29.0	26.8	30.1	30.8	31.2	34.0	32.6	29.7	30.4

[1] Data from 1995 to 2007 are weighted for child selection
[2] From 2003 data was also weighted for non-response. For consistency with previous years, 2003 to 2007 data shown here are weighted for child selection only
[3] Data shown for 2003 to 2007 here is weighted for non-response and child selection (HSE samples a maximum of 2 children per household so in households with more than 2 children each child has a lower probability of selection. Weighting corrects for this.)
[4] Categories are independent, i.e. overweight does not include those who are obese. Overweight was defined as ≥ 85th < 95th UK BMI percentile; obese was defined as ≥ 95th UK BMI percentile

Table 3. Body Mass Index (BMI)[1] among adults[2], 1993 to 2006 in the Health Survey for England 2007.

	Percentages														
	Unweighted[3]										Weighted[3]				
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Underweight	1.6	1.7	1.8	1.7	1.5	1.7	1.7	1.5	1.4	1.7	1.8	1.6	1.6	1.6	1.6
Normal	45.5	45.2	43.7	42.2	41.6	40.6	40.4	38.6	37.0	37.7	37.8	36.7	37.9	36.8	37.7
Overweight	38.0	37.4	38.1	38.7	38.5	38.3	38.0	38.8	39.2	38.1	37.9	38.8	37.3	37.6	36.7
Obese	14.9	15.7	16.4	17.5	18.4	19.4	20.0	21.2	22.4	22.5	22.6	22.9	23.2	23.9	24.0
Overweight including obese	52.9	53.1	54.5	56.2	56.9	57.7	57.9	60.0	61.6	60.6	60.5	61.8	60.5	61.6	60.8
Morbidly obese	0.8	1.0	0.9	0.9	1.6	1.3	1.4	1.5	1.7	1.8	1.9	1.7	1.8	2.1	1.8

[1] Using the following BMI definitions: Underweight: less than 18.5 kg/m^2; normal: 18.5 to less than 25kg/m^2; overweight: 25 to less than 30 kg/m^2; obese 30 kg/m^2 or more; overweight including obese 25 kg/m^2 or more; morbidly obese: 40 kg/m^2 or more

[2] Adults aged 16 and over with a valid height and weight measurement

[3] Data from 2003 onwards have been weighted for non-response.

96. Obesity increases the risk for a number of diseases (see Table 4 for an overview).

Table 4. Summary of associations observed in prospective studies between obesity and subsequent ill health [86].

Association for increased risk	Disease outcome
Relative risk >3	Type 2 diabetes Insulin resistance Hypertension Dyslipidaemia Breathlessness Sleep apnoea Gall bladder disease
Relative risk about 2-3	Coronary heart disease or heart failure Osteoarthritis (knees) Hyperuricaemia and gout Complications of pregnancy, e.g. pre-eclampsia
Relative risk about 1-2	Cancer, e.g. oesophagus (adenocarcinoma), colorectum, breast (postmenopausal), endometrium and kidney[87;88] Impaired fertility/polycystic ovary syndrome Low back pain Increased risk during anaesthesia Fetal defects associated with maternal obesity[89]

Genetics of obesity

97. Many studies have examined possible hereditary factors predisposing to human obesity that influence energy expenditure. It is notable however that, thus far, all monogenic defects identified as causing human obesity disrupt hypothalamic pathways and have an effect on satiety and food intake[90]. Genome-wide association studies have shown genetic variation in the *FTO* gene (a 2-oxoglutarate-dependent nucleic acid demethylase gene[91]) to be associated with fat mass and obesity across multiple populations[92-97], although only accounting for a small amount of the variation. In 13 cohorts, with a total of 38,759 participants from the UK and Finland, the 16% of adults who had the AA genotype for the *FTO* gene weighed about 3 kg more and had a 1.67 fold increased odds of obesity compared with the non-carriers (TT genotype)[94]. The genetic variation in the *FTO* gene has also been implicated in appetite control[98-101], but not energy expenditure, after adjustment for body size[100;102;103]. The association between *FTO* variants and obesity has been observed to be reduced in those who are more physically active[104] and accentuated in those who are less physically active[105]. Inter-individual differences in susceptibility to obesity, therefore, may be determined, in part, by genetic variants impacting on appetite control in the presence of environmental exposures.

The influence of physical activity and diet on the regulation of body weight

98. See Appendices 7 and 8 for a detailed discussion. A summary of the main points from these

sections is given here.

99. Body fat is gained when energy intake exceeds total energy expenditure over time. PAEE is the most variable component of TEE, and is amenable to modification, so changes in PAEE may affect risk of weight gain.

100. Methodological constraints are a severe limitation in defining the role of physical activity in the regulation of body weight, e.g. studies and surveys mostly rely on subjective measures of reported physical activity. Proxy measures of population-level physical activity trends suggest that changes in activity in domestic life, work and travel have coincided with the increase in prevalence of obesity. A review of the available evidence from prospective cohort studies suggested that, on balance, increased physical activity and decreased sedentary behaviour may be protective against relative weight and fatness gains; however, the results were mixed and the associations that were identified were generally of a small magnitude[106]. Evidence from studies using objective measures of physical activity, especially DLW-derived measures of PAEE, and trials of the primary prevention of weight gain is inconsistent. The available data are insufficient for a definitive conclusion on how much physical activity is required to prevent unhealthy weight gain

101. Methodological constraints are also a severe limitation in defining the role of diet and its composition in the regulation of body weight, e.g. limitations in the accurate assessment of dietary exposures and under-reporting. Overall, the evidence of diet composition (the relative proportions of macronutrient and micronutrient densities or energy density) affecting risk of weight gain is weak. A prolonged excess energy intake is, however, fundamental to weight gain and the development of obesity. Household survey data (from the Expenditure and Food Survey, EFS) suggests that there has been a decrease in average daily energy intakes over the same time period in which there has been a large increase in the prevalence of overweight and obesity. Caution must be used in interpreting these temporal changes however since problems of under-reporting will be exacerbated during a time when the population has gained weight as this increases the proportion of participants likely to under-report. The instruments used to assess household consumption in these surveys are also not very accurate. The NDNS, in which food consumption is measured at the level of the individual and under-reporting is considered, also shows average energy intakes to have decreased between 1986/7 and 2000/1. On both occasions 7 day weighed diaries were used. This methodology is considerably more robust than that used in the EFS.

102. Energy flux, as well as energy balance, needs to be considered. It has long been hypothesised that the mechanisms controlling energy balance may be more sensitive in individuals with higher levels of physical activity, while in sedentary individuals there is a threshold of physical activity below which these mechanisms become imprecise leading to obesity[107]. There is some indirect evidence that the coupling between energy expenditure and energy intake may be less at low levels of physical activity [108;109].

3 Approach used to derive energy reference values

Summary of approach used by SACN to determine EARs

103. The SACN Framework for the Evaluation of Evidence[16] was used as the basis to identify and assess published evidence of total energy expenditure from which to estimate energy reference values. The majority of studies identified were cross-sectional studies in healthy human populations of infants, children and adults and provided mean TEE values for the study population. Two large datasets of individual TEE values for adults were subsequently obtained from the USA, the OPEN and Beltsville studies (as described in paragraph 131 and Appendix 10). Some prospective cohort studies were also found and any potential link between energy intake and risk of ill health has been mainly drawn from these. Only studies using the doubly-labelled water (DLW) method to measure TEE were considered by the Committee as this represents the most accurate method for assessing TEE in free-living populations. Priority was also given to studies in well-characterised populations (age, gender, weight, height or BMI etc) and where BMR (see paragraphs17, 63 and 64) had been measured directly rather than estimated from prediction equations. Studies of extreme energy users, such as elite athletes, and those based on populations which were not representative of the UK (such as ethnic minorities not commonly seen in the UK) were given less emphasis.

104. For adults aged 19 - 65 years and children aged between 3 - 18 years, SACN examined a number of different approaches to setting EARs. The Committee first explored regression modelling. Mean TEE values from the data set of DLW studies were used to develop regression equations of TEE against age, weight and gender for different age groups. However, as discussed above (see paragraphs 68-71) this approach is limited because of the inability of TEE prediction models to account for an important source of variation in TEE, namely PAEE. As a result, the regression approach was abandoned in favour of the factorial model in which TEE is predicted from BMR x PAL (see paragraphs 65-67).

105. BMR for children and adults is predicted with existing equations based on weight, height (in some cases), age and gender. The PAL values for adults, as median, 25th and 75th centiles, are those calculated directly from individual TEE values reported in the OPEN and Beltsville datasets. The PAL values for children >1 year are those calculated directly from a dataset of published DLW studies which were aggregated on the basis of study mean values.

106. For infants, the Committee agreed that the reference values stated in the FAO/WHO/UNU report[110] should be used due to a lack of new data. Pregnant and lactating women were considered separately.

Energy reference values for infants, children and adolescents

Energy cost of growth

107. TEE measured using the DLW technique includes the energy expended in tissue synthesis. Thus only the cost of energy deposited in growing tissues should be considered

when calculating the energy reference values for infants, children and adolescents. For infants, such costs are relatively high and change during the first year of life (see paragraphs 114 and 115 and Table 5). The costs of energy deposited in growing tissue are therefore specifically identified as an addition to estimates of TEE. For older children and adolescents, growth costs are much less and can be accounted for by a simple adjustment to the factorial prediction of TEE from BMR x PAL.

Infants 0 – 12 months of age

108. The energy reference values presented for infants are derived from the values prepared by Butte[110] for the FAO/WHO/UNU Expert Consultation[13] in which energy requirements during infancy were estimated from TEE measured by the DLW method in healthy, well-nourished, non-stunted infants born at full term with adequate birth weight, and growing along the trajectory of the WHO reference standard. Estimates of energy deposition were based on measured protein and fat gains.

Energy expenditure

109. A simple prediction equation for TEE as a function of body weight was derived from a longitudinal study of TEE with DLW measures conducted at three month intervals for the first two years of life on 76 infants (40 breastfed and 36 breast milk substitute fed)[38].

TEE (MJ/day) = – 0.416 + 0.371 kg n = 320, r = 0.85, see = 0.456 MJ/day (109 kcal/day)

110. This was very similar to the relationship between TEE and weight derived from an analysis of 13 published studies with DLW performed on a total of 417 infants aged 0-12 months using the *mean* values for TEE and body weight[110].

111. Exclusive breastfeeding to the age of six months with continued breastfeeding as part of a progressively varied diet is recommended for all healthy infants[77]. The energy expenditure in breast milk substitute-fed infants has been shown to be higher than breastfed infants[38;111;112], indicating differences in TEE between feeding groups over the first year of life that diminish thereafter; there are also differences in growth patterns between breast milk substitute-fed and breastfed infants[77;113;114].

112. TEE for breastfed and breast milk substitute fed infants may be predicted from body weight. Due to the differences described above, separate regression equations for TEE as a function of weight were derived for these two groups[110]. The between individual CV of TEE among individuals ranged from 15 to 21% (18% average) or from 13 to 17% for TEE/kg (15% average). The equations to predict TEE from body weight are as follows:

TEE for breastfed infants:

TEE (MJ/day) = 0.388 Weight (kg) – 0.635; standard error of estimate (SEE) = 0.453 MJ/day (108kcal/day)
TEE (kcal/day) = 92.8 Weight (kg) - 152; SEE = 0.108

TEE for breast milk substitute-fed infants:

TEE (MJ/day) = 0.346 Weight (kg) – 0.122; SEE = 0.463 MJ/day (110kcal/day)
TEE (kcal/day) = 82.6 Weight (kg) - 29.0; SEE = 0.110

113. Weights substituted in these equations were derived from the WHO growth standard[115] discussed below in paragraph 178.

Energy deposition

114. Growth costs were calculated as the deposited energy accrued during normal growth. These were estimated from a multi-component body composition model (total body water, total body potassium and bone mineral content)[41] based on a modified version of Fomon's term infant reference[116] describing changes in body composition during growth. Estimates of protein and fat gain over 3 month periods were used to predict energy accrued per g weight gain which was then used to predict growth costs at monthly intervals.

Table 5. Energy content of tissue deposition of infants[110]

Age interval (months)	Protein gain (g/d)	Fat mass gain (g/d)	Energy deposited in growing tissues (kJ/g)
Boys			
0-3	2.6	19.6	25.1
3-6	2.3	3.9	11.6
6-9	2.3	0.5	6.2
9-12	1.6	1.7	11.4
Girls			
0-3	2.2	19.7	26.2
3-6	1.9	5.8	15.6
6-9	2.0	0.8	7.4
9-12	1.8	1.1	9.8

Energy equivalents: 1g protein – 23.6kj (5.65 kcal); 1g fat = 38.7kj (9.25kcal)

115. Using this model, the estimate of energy deposited in new tissue fell from about 26 kJ/g (6.3 kcal/g) at 0-3 months to about 10 kJ/g (2.3 kcal/g) at 9-12 months (see Table 5). These values were applied to the weight velocities observed in the WHO Growth Standards for infants[115] to estimate the rates of energy deposition at monthly intervals (see Tables 12 and 13 for weight velocities). These predictions of energy deposited during growth derive from a relatively small study by Butte *et al* [41] which was "validated" against other datasets[110]. It is assumed that these values for the energy deposited in new tissue are appropriate for children growing according to the WHO weight velocity values, even though in the original study[41] the pattern of breastfeeding followed was not fully described and the growth of infants did not fully reflect the WHO growth trajectory[115]. Also information is lacking on the extent of any differences in body composition during growth between breastfed and breast milk substitute-fed infants, although in the study by Butte *et al*[41] no significant differences were noted.

Energy reference values for children and adolescents aged 1-18 years

116. The energy reference values for boys and girls aged 1-18 years were calculated as TEE plus deposited energy costs using a factorial model BMR x PAL with PAL adjusted for growth in terms of a 1% increase (see paragraph 122).

117. The BMR values for children and adolescents are predicted from the Henry prediction equations[57] using mean weights indicated by the WHO growth standards[115] (ages 1 to 2 years) and the UK 1990 reference weights for ages 2 to 18 years (see Appendix 3 for details).

Identifying PAL values

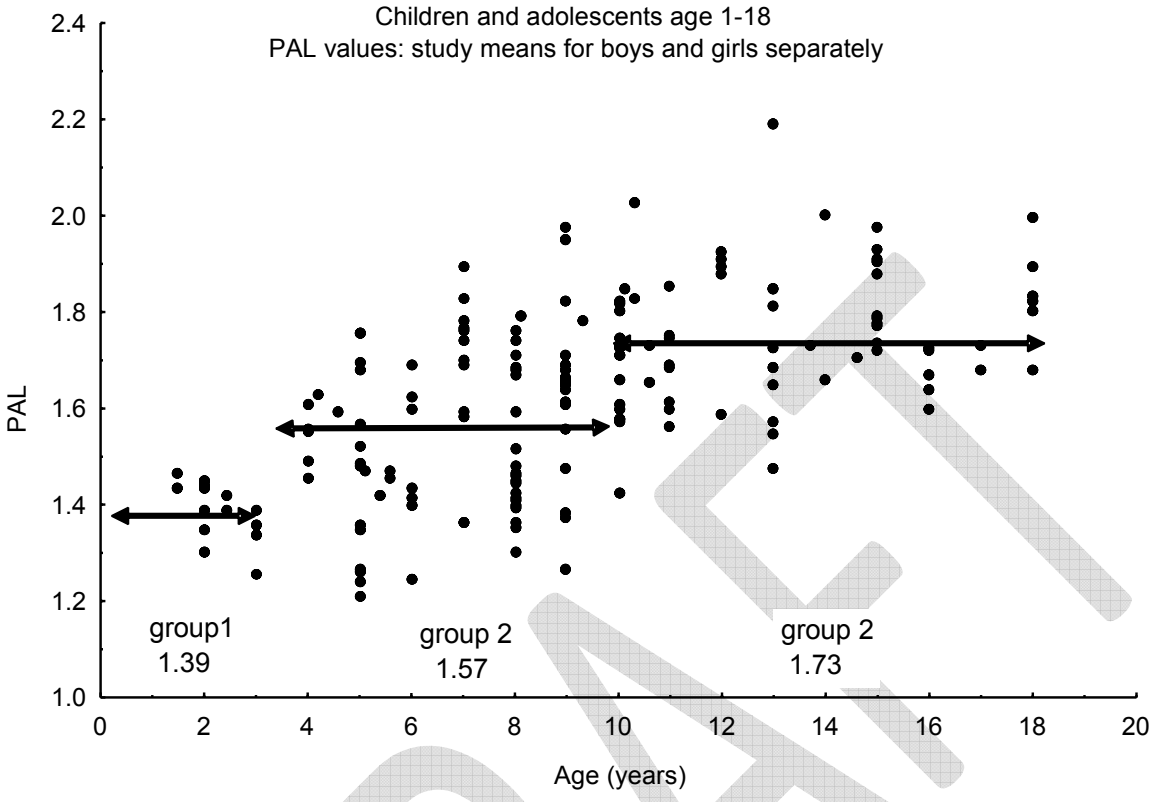
118. PAL values were identified from an analysis of DLW measures of TEE. The objective of the analysis was to identify specific age ranges of children within which variation with age was less than variation between individuals. This would allow PAL to be defined for these age-range groups in terms of its distribution: i.e. as the median, 25th and 75th centile range values. The analysis also examined the need to identify gender-specific PAL values.

119. A data set was compiled of all published DLW studies of children aged >1 year (see Appendix 9 for details). All studies were tabulated according to mean values for boys and girls for specific age groups. This resulted in 170 data points as study means representing a total of 3502 individual measurements (2082 females, 1420 males).

120. For all studies which did not report BMR, BMR values were calculated from the Henry equations for weight and height or weight alone if no height was reported (see Appendix 3). PAL values were calculated from TEE and either the reported or calculated BMR values.

121. The analysis revealed no influence of gender but an increase in PAL values with age as shown in Figure 2. From an early age, however, there was a wide range of study mean PAL values so that variation in PAL at any age was much greater than variation with age itself. As a result, three age groups were identified within which the distribution of PAL values could be identified: 1-3 years, >3-<10 years and 10-18 years. To some extent, these age ranges reflect important periods of growth and development which could influence behaviour and energy requirements. They also correspond to the age ranges within which BMR prediction equations have been generated for both the Schofield and Henry prediction equations. Median, 25th centile and 75th centile PAL values were identified for each of these groups and are shown in Table 6.

Figure 2. PAL values for children and adolescents as a function of age. Median values for the indicated age ranges are shown



Each point represents a single age group reported in a single publication or in publications which list mean values for each of several age groups. The publications from which the data points are derived and the mean values in Table 6 are listed in Appendix 9.

Table 6. PAL values for the age groups 1-3, >3-<10 and 10-18

	Age					PAL								
	N	mean	sd	Min	Max	mean	sd	Min	10th centile	Q25	**Median**	Q75	90th centile	Max
1-3	14	2.3	0.54	1.5	3.0	1.39	0.06	1.26	1.30	1.35	**1.39**	1.43	1.45	1.46
>3-<10	85	7.0	1.87	4.0	9.3	1.56	0.14	1.21	1.35	1.42	**1.57**	1.69	1.77	1.98
10-18	71	13.0	2.38	10.0	18.0	1.75	0.13	1.42	1.58	1.66	**1.73**	1.85	1.91	2.19

Adjusting for growth

122. Growth costs should be considered in terms of deposited energy since the metabolic cost of growth is part of the observed TEE. Deposited energy accounts for a relatively small overall proportion of the total energy needs of children at all ages after the first year of life (see Appendix 9). In the context of a factorial model of requirements the simplest approach is an adjustment of PAL, as suggested by FAO/WHO/UNU[13], which in effect represents growth as a fixed proportion of the overall energy requirement. Growth costs calculated as a

percentage of energy requirement are on average (1-16y), 0.98% (min=0.4%, boys, 0.05%, girls; max= 1.37%, boys, 1.59%, girls). A single average growth value calculated as 1% of energy requirements throughout the age range will result in maximum errors for the overall energy requirement during the peak growth phase for older children of an underestimate of 0.6% energy requirement for girls or 0.4% for boys with an overestimate by similar amounts as growth slows at the end of teenage years. These were viewed as acceptable errors given the overall variation in PAL values between children. Growth costs were therefore accounted for by a 1% adjustment of PAL values for each age group and these adjusted values are shown in Table 7.

Table 7. PAL values for use in calculation of energy requirements of children and adolescents, adjusted for growth

Age group	PAL*		
	Q25	**Median**	Q75
1-<3	1.36	**1.40**	1.45
3-<10	1.43	**1.58**	1.70
10-18	1.68	**1.75**	1.86

** PAL adjusted for growth (=PALx1.01)*

Calculating energy reference values

123. Energy reference values can be calculated for boys and girls aged 1-18 years as adjusted PAL x BMR. BMR values are calculated from mean weights indicated by the WHO growth standards[115] (ages 1 to 2) and the UK1990 reference weights for ages 2-18 years. Growth-adjusted PAL values representing the 25th, median and 75th centiles of the PAL distributions for each age group (1-<3, 3-<10 and 10-18), are then used to calculate energy reference values for boys and girls, for each year.

Energy reference values for children outside the expected range of activities and the effects of additional physical activity on energy requirements

124. The energy reference values calculated from the adjusted median PAL value shown in Table 7 are the best estimates for children and adolescents with average levels of physical activity. Children with greater or lesser activity levels are likely to require more or less energy respectively and for these groups the 25th and 75th centile PAL values will be appropriate. The rationale for this is discussed in more detail below (paragraph 140).

125. In children who change their activity pattern, by for example engaging in sporting activities for the first time, energy requirements will increase. Examples of how provision can be made for this are discussed below (paragraph 141).

Energy reference values for adults

126. The approach adopted for the determination of energy reference values for this age group

was to utilize a factorial model based on PAL x BMR with the PAL values identified from an analysis of suitable DLW measures of TEE.

Predicting the BMR

127. As already indicated there is a range of equations currently used to predict BMR. In 1991, COMA used the Schofield equations[57] to predict BMR values of adults[1]. The prediction equations of Henry[57] represent the largest and most rigorously tested equations and these have consequently been used to calculate the BMR values for adults in this report (see Appendix 3 for details).

Identifying PAL values

128. The approach was to identify a dataset of DLW measures of TEE which could serve as a reference distribution of TEE and PAL values from which energy reference values for the UK adult population could be predicted. An initial survey of all published and other available DLW measures of TEE in healthy adults identified published studies which could be utilized in terms of study means. Also considered were individual data points from:

- a data set of individual values drawn from the NDNS (n=66) and Low Income Diet and Nutrition Survey (n=36), and
- the DLW dataset (n=767) assembled for the US DRI report[20] which includes most of the UK studies published up to the writing of that report.

129. Subjects were not recruited to these studies explicitly as a representative sample of the UK or any other adult population, with the exception of the NDNS which randomly selects participants to be representative of the UK population while recognising that there may be recruitment bias (see paragraph 62). All of the studies included a wide range of BMI and a reasonable age distribution but several involved investigations of physical activity measurement devices (e.g. accelerometers) and specifically recruited subjects following relatively high activity lifestyles. Although these studies illustrated the overall extent of the variation in PAL values, especially its upper and lower limits and its likely response to changes associated with specific activity programmes, the suitability of a combined data set was a cause for concern.

130. The large DLW dataset assembled for the DRI report[20] comprised individual values supplied to the DRI committee by the authors of many of the individual studies. It comprises 767 adults aged ≥18 years, 360 overweight/obese and 407 of normal BMI with an under representation of middle aged and very old. The extent to which it is a representative sample is briefly reviewed within the DRI report which comments: "Since the DLW data were not obtained in randomly selected individuals…, they do not therefore constitute a representative sample of the populations of the United States and Canada. However, the measurements were obtained from men, women, and children whose ages, body weight, height, and physical activities varied over wide ranges, so they provide an appropriate base to estimate energy expenditures and requirements…. A few age groups are underrepresented in the data set and interpolations had to be performed in these cases. Thus, while the available DLW data set used is not entirely satisfactory, it nevertheless offers the best currently available information".

131. Subsequent to publication of the DRI report, two large population-based studies of

energy expenditure measured using DLW have been published, the OPEN study[60;61] and the Beltsville study[62] (see Appendix 10 for details). The OPEN study involved healthy volunteers (n=451; 245 men and 206 women) aged 40–69 years. About 85% of volunteers were white with the remainder mainly black or Asian. The Beltsville study involved healthy volunteers (n= 478) aged 30–69 years. The subjects were predominately non-Hispanic white and were distributed evenly by sex and approximately by age. Both studies recruited subjects from Washington DC and were judged to be representative of the US population on the basis of their demographic characteristics, which are also considered similar to the current UK population. Individual PAL values were kindly made available to SACN from both studies. The OPEN study did not measure BMR, so BMR has been calculated using the Henry BMR prediction equations [57] based on weight and height. The distribution statistics for PAL within these two large datasets are shown in Table 8.

Table 8: Distribution of PAL values in the OPEN and Beltsville studies

Distribution boundaries	OPEN (n=451; age 40-69y)	Beltsville (n=478; age 30-69y)
Minimum	1.01	1.01
10th centile	1.40	1.32
lower quartile	1.49	1.46
median	1.61	1.62
upper quartile	1.77	1.78
90th centile	1.92	1.96
Maximum	2.61	2.34

132. When the OPEN and Beltsville cohorts were combined, there were similar numbers of men (48%) and women (52%). Within the combined cohort, 39% were classified as overweight and 25% obese, which is similar to the proportions observed in the UK Health Surveys (see Obesity section above).

133. The distribution of PAL values within the combined dataset (n=929 individual measures), was 1.01 to 2.61, as shown in Table 9. Investigation of the range of PAL values which can be sustained by healthy individuals who are ambulatory to some extent, and with overall levels of physical activity which are sustainable indicated a range of 1.38-2.5 (see Appendix 2) with a value of 1.27 representing a minimal survival requirement: i.e. minimal movement in waking hours as suggested by FAO/WHO/UNU in 1985[33]. Thus values below 1.27 can be assumed to reflect either methodological error or to be non ambulatory individuals, highly dependent on others, or those with an unsustainable lifestyle. Similarly subjects with PAL values >2.5 can be assumed to be participating in very high activity levels during the measurement period which are unrepresentative of usual activity. Thus the combined data set was trimmed for PAL values ≤1.27 or > 2.5. This removed 1 subject with a PAL value greater than 2.5 and 38 subjects with PAL values less than1.27. However the trimming had a minimal influence on the distribution characteristics increasing the median PAL value from 1.62 to 1.63. The skewed distribution with subjects clustered at the lower end of the range is clearly apparent in Figure 3. The PAL values selected to predict energy reference values for the adult population are highlighted. The use of the 25th and 75th centile values is discussed below.

134. The influence of BMI on PAL values within the combined dataset was investigated by regression analysis (see Appendix 8 for detail). Regression of PAL on BMI was non significant (p=0.64 for slope: R^2 less than 0.1%) indicating that energy reference values can be defined independently of BMI status.

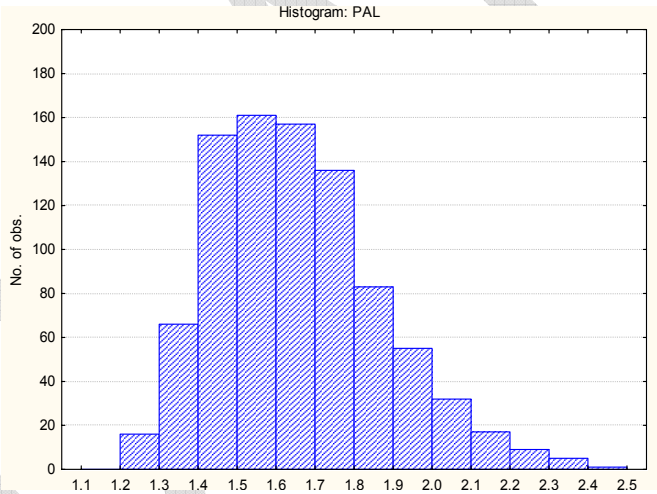
135. Regression analysis did show that PAL values decrease slightly with age. However age explained <1% of the variance (r^2 =0.004), and since the slope is shallow, age has a minor influence on PAL, i.e. PAL = 1.69 at 30 years and 1.63 at 70 years. This indicates that energy reference values can be defined independently of age at least to the age of 70.

Table 9. PAL value statistics for the combined OPEN and Beltsville data sets

	N	Mean	SD	Min	10th centile	25th centile	Median	75th centile	90th centile	Max
All	929	1.64	0.23	1.01	1.36	1.48	1.62	1.78	1.95	2.61
Trimmed[a]	890	1.66	0.21	1.27	1.40	**1.49**	**1.63**	**1.78**	1.96	2.50

[a], subjects with PAL values < 1.27(n=38) and >2.5 (n=1) excluded

Figure 3. Distribution of PAL values for trimmed combined OPEN and Beltsville data sets



Calculating energy reference values

136. Specific values of TEE and the consequent EAR are calculated from PAL x BMR as a function of age, gender and BMI. PAL values are those highlighted in Table 9: i.e. values representing the median (1.63), and 25th (1.49) and 75th centile (1.78). BMR is calculated with the Henry equations.

Energy reference values for older adults

137. Age-related changes in lifestyle and activity are very variable and many older people exhibit relatively high levels of activity[117]. In a cohort (n= 302) of community-dwelling US older adults (aged 70-82 years) who are described as high-functioning, able to independently perform activities of daily living, and with no evidence of life-threatening illnesses, a wide variation of PAL values was observed. The mean PAL values for tertiles of PAEE were

1.48, 1.68 and 1.94. The overall mean PAL value for this group, 1.70, was slightly higher than that of the combined OPEN and Beltsville cohort of younger adults (mean PAL =1.64).

138. In advanced age, PAL values can be very low. In a group of 21 Swedish men and women aged 91-96 years of age, all free- and independently-living, and termed healthy, all living a quiet life (some not having been out of doors for years), PAL values were on average 1.38 (1.13-1.65 after trimming for PAL values <1.1 on the basis of comments that some BMR values may have been too high)[32]. Another study in free-living British men (n=23; all over 75 years of age) observed a mean PAL value of 1.5[118].

139. Taken together these data indicate that it is difficult to generalise about the energy requirements of older adults other than that older adults are unlikely to differ from younger adults whilst general health and mobility are maintained. However in advanced age with reduced mobility it can be assumed that PAL values are likely to be lower.

Energy reference values for children, adolescents and adults outside the expected range of activities

140. The PAL values identified in the preceding sections do not indicate any particular level of physical activity or lifestyle because as discussed in Appendix 2 it has proved very difficult to predict PAL values of individuals as a function of lifestyle or even measured physical activity. The median PAL value shown in Table 9 represents the midpoint of the distribution observed in the reference population and as such is the best estimate of the average activity level for the population. This value is the assumed population level, in the absence of other information on activity. However it is recognised that subject groups who appear obviously more or less active than the average can be identified and should be considered and this is why the 25th and 75th centile PAL values have been identified. These centile bands represent the overall range of PAL values observed within the lower or upper half of the population or an approximation of the midpoint value for the less active or more active population. The difference between these centile values and the median is 9% for adults and for children aged >3-<10, 5% for adolescents and only 3% for the youngest children. These values can be compared with the slightly greater range of ± 10% identified as the basis for the higher or lower than average activity levels identified by FAO/WHO/UNU in their analysis of energy requirements of children and adolescents. Thus the 25th and 75th centile PAL values represent activity levels of those who in general terms are less or more active than average.

Effects of additional physical activity on energy requirements

141. Although the prediction of PAL values associated with a specific lifestyle cannot be made with any certainty, predictions of the likely additional energy cost of well defined specific activities can be made with reasonable confidence. Estimates of the likely changes in PAL for a range of activities deriving from theoretical calculations and from observed effects to the change in PAL for 10 minutes and 1 hour of activity, or the adoption of a high level physical activity training programme are summarised in Appendix 2. Some examples are shown in Table 10. These are the likely increases in energy expenditure (and hence requirements) expressed as the change in PAL for the listed activities for individuals leading lives with little physical activity but maintaining body weight and providing no compensatory reduction in other activities or increase in energy intake occurs. These values have been derived primarily from studies on adults but there is no reason to believe that they will be substantially different for children and adolescents.

*Table 10: Examples of changes in PAL associated with increased activity**

Change in PAL	Activity
0.15	30 minutes of moderate intensity activity on 5 or more days of the week[1]
0.2	60 minutes brisk walking (brisk =>6<7.5kmph, (=>4<5mph)) daily
0.3	60 minutes of active sport, (i.e. jogging at 9km/hr (6mph)), 5 times per week
0.4	60 minutes jogging at 9km/hr (6 mph) daily
0.6	An intense aerobic exercise programme associated with training for competitive sport daily

* More examples are shown in Appendix 2

[1]Current recommendations from UK health departments regarding physical activity in adults

Energy reference values for energy during pregnancy and lactation

142. The energy requirements for pregnancy and lactation are calculated as increments to be added to the mother's EAR. These are based on singleton pregnancy; insufficient evidence is available on the energy costs of multiple pregnancies.

143. Ideally, women should begin pregnancy at a healthy weight (BMI 18.5-24.9). Women who are overweight or underweight at the beginning of pregnancy are at risk of poor maternal and fetal outcomes. The DRVs for pregnancy and lactation are for women of healthy weight.

144. Adolescents who become pregnant must meet the dietary requirements imposed by growth associated with their age, in addition to the demands of pregnancy and lactation.

Energy costs of pregnancy

145. The energy costs associated with the maintenance of a normal pregnancy arise from increases in maternal and feto-placental tissue mass, the rise in energy expenditure attributable to increased basal metabolism and changes in the energy cost of physical activity[43].

146. Gestational weight gain is the major determinant of the incremental energy needs during pregnancy. It determines not only energy deposition, but also the increase in BMR and TEE resulting from the energy cost of moving a larger body mass. The WHO Collaborative Study on Maternal Anthropometry and Pregnancy Outcomes[119] defined birth weights and maternal weight gains associated with lower risk of fetal and maternal complications. Birth weights between 3.1 and 3.6 kg (mean, 3.3 kg) were associated with the optimal ratio of maternal and fetal health outcomes. The range of gestational weight gains associated with birth weights greater than 3 kg was 10–14 kg (mean, 12 kg).

147. The tissue deposited during pregnancy includes the products of conception (fetus, placenta, and amniotic fluid), maternal tissues (uterus, breasts, blood, and extracellular extravascular fluid) and maternal fat reserves. A theoretical model has previously been used to estimate the energy requirements during pregnancy[120]. This assumed an average gestational weight gain of 12.5 kg (0.9 kg protein, 3.8 kg fat, and 7.8 kg water), an efficiency of energy utilization of 90% and a mean birth weight of 3.4 kg. The total energy cost of pregnancy was estimated to be about 330 MJ (80,000 kcal).

148. Longitudinal studies of body composition during pregnancy in well-nourished women have observed a mean gestational weight gain of 13.8 kg associated with an estimated total energy cost of about 370 MJ (88,000 kcal)[43].

149. In studies of well-nourished women, BMR has on average been observed to increase in the first, second and third trimesters by 2.5, 10.8 and 24.0%, respectively[43]. There is, however, considerable variation in the cumulative increase in BMR.

150. In under-nourished populations, adaptive changes in BMR, and in the amount of additional maternal fat stored during gestation, can make a profound difference to the overall energy needs of pregnancy[121]; however, this may be associated with inadequate weight gain and poor birth, and later health, outcomes. It is unclear to what extent adaptive changes in BMR occur in well-nourished populations, but the increase in BMR during pregnancy has been observed to vary in response to pre-pregnancy body fat content, with larger increases observed in those having a higher percent FM[42;122].

151. The TEE of pregnancy has been measured longitudinally using DLW techniques in well-nourished free-living women during pregnancy[42;123-126]. TEE increased throughout pregnancy in proportion to the increase in body weight. TEE increased by 1, 6, and 19%, and weight increased by 2, 8, and 18% over baseline in the first, second and third trimesters, respectively. The increments in TEE (0.1, 0.4 and 1.5 MJ/day in the first, second and third trimesters, respectively) are similar to the increments observed by 24-hour calorimetry [43]. The average gestational weight gain was 13.8kg, but for an average gestational weight gain of 12 kg the corresponding values would be 0.08, 0.35 and 1.30 MJ/day.

152. In the latter half of pregnancy, body weight increases result in increased energy costs for weight-bearing activities; however, women may compensate for this by reducing the pace or intensity with which the activity is performed[43;122]. Changes in physical activity during pregnancy may partly compensate for the increased energy costs[43;122]. The extent to which women are able to modify habitual physical activity patterns during pregnancy will be determined by socioeconomic and cultural factors specific to the population; women who are sedentary prior to pregnancy will have little flexibility to reduce their level of physical activity.

153. Changes in physical activity energy expenditure (TEE–BMR) during pregnancy are highly variable, but when measured longitudinally by DLW in well-nourished women averaged -2, 3 and 6% in the first, second and third trimesters, respectively, relative to pre-pregnancy values[43]. Because of the larger increment in BMR, PAL declined from 1.73 prior to pregnancy to 1.60 in late gestation in well-nourished women[43].

154. In women with a pre-pregnancy BMI between 19.8 and 26.0, reductions in physical

activity energy expenditure were observed as pregnancy progressed. These did not, however, totally compensate for increases in BMR and energy deposited in maternal and fetal tissues; thus, increases in dietary energy intakes were required as pregnancy progressed[42].

155. The energy cost of pregnancy is not equally distributed over pregnancy[43]. Rates of weight gain of 1.6 kg in the whole first trimester, 0.45 kg per week in the second trimester and 0.40 kg per week in the third trimester suggest a distribution of 11, 47 and 42% in the first, second and third trimesters, respectively. The increases in BMR and TEE are most pronounced in the second half of pregnancy.

156. The total energy cost of pregnancy can be estimated from the increment in BMR and energy deposition and from the increment in TEE and energy deposition. The two approaches provide slightly different distributions, but the average increment is 430, 1375 and 2245 kJ/day, for the first, second and third trimesters, respectively. When applied to the WHO Collaborative Study on Maternal Anthropometry and Pregnancy Outcomes recommended mean gestational weight gain of 12kg[119], the estimated energy cost of pregnancy is 375, 1200 and 1950kJ/day for the first, second and third trimesters, respectively. This is based on the assumption that increments in BMR and TEE were proportional to weight gain

157. Most dietary studies in well-nourished women, however, have revealed no or only minor increases in energy intake that only partially covered the estimated energy cost of pregnancy. An analysis of available data from longitudinal studies in populations with average birth weights greater than 3 kg revealed a cumulative reported intake of only 85 MJ (0.3 MJ/day) over the whole of pregnancy or 25% of the estimated needs[122].

158. The FAO/WHO/UNU[13] report recommends an increase in food intake of 1.5MJ/day in the second trimester and of 2.0MJ/day in the third, based on a gestational weight gain of 12kg and specific for women in societies with a high proportion of non-obese women who do not seek prenatal advice before the second and third month of pregnancy.

159. The 1.5MJ/d increment for the second trimester represents a summing of 1.2MJ/d and 0.35MJ/d (for first trimester) on the grounds that women may not know they are pregnant until the second trimester. This is pragmatic, but there is no evidence that retrospective supplementation of this type alters outcome and it seems likely that in circumstances of unconstrained food intake increased requirements would have been achieved already through an increase in appetite.

160. The US energy DRI for pregnancy[20] used a DLW database of individual energy expenditure measures of pregnant women with pre-pregnancy BMI values of 18.5 up to 25; the measures were obtained from studies in British[125;127] Swedish[123] and North America[126] women. Gestational weight gain was between 11.6 and 13.5 kg. The median change in TEE was 33.5 kJ (8 kcal) per week of gestation with a large range of -238 kJ (-57 kcal) to 448 kJ (107 kcal) per week. The value of 33.5 kJ (8 kcal) per week was supported by a subsequent study which reported that TEE, as measured by DLW, increased linearly at a similar mean rate of 31 ± 42.7 (7.4 ± 10.2 kcal) per week of gestation in women with pre-pregnancy BMI values of 19.8 to 26.0 (Butte, 2004)[42]. The total energy deposition during pregnancy was estimated to be 753 kJ/day (180 kcal/day). Thus the estimated energy requirement was derived from the sum of the TEE of the woman in the non-pregnant state plus a median

change in TEE of 33.5 kJ/wk (8 kcal/wk) plus the energy deposited during pregnancy. For the first trimester no increase in energy intake was recommended, on the basis of only small changes in TEE and weight gain. For the second and third trimesters the energy deposition rate of 753 kJ/day (180 kcal/d) was added to the increase in TEE expected at 20 weeks (672 kJ (160 kcal)) and 34 weeks (1142 kJ (272 kcal)) to give the incremental values of 1.43MJ/day (340 kcal/day) and 1.9 MJ/day (452 kcal/day) respectively.

161. The COMA DRV report recommended an increment in EAR of 0.8MJ/d above the pre-pregnant EAR only during the last trimester. It was noted that women who were underweight at the beginning of pregnancy, and women who did not reduce activity, may need more.

162. The Committee note that an increasing proportion of women in the United Kingdom enter pregnancy at a weight exceeding the healthy range and that this may place them and their babies at increased risk. The Committee consider it unlikely that women require extra energy in the 1st trimester of pregnancy and further note that compensatory changes in energy expenditure during the 2nd and 3rd trimester are likely to mean that increased energy intake is not necessary. Having reviewed the available evidence, SACN agreed that the EAR for pregnancy established by COMA, i.e. an additional intake of 0.8MJ/d (191 kcal/d), remained appropriate.

Energy cost of lactation

163. The amount of milk produced, the energy content of the milk and the energetic efficiency of milk synthesis theoretically determine the energy cost of lactation. There is little evidence of energy conservation, i.e. changes in BMR, TEF or the energy cost of certain physical activities, compensating for these energy costs during lactation in well nourished women[43]. Fat stores that accumulate during pregnancy may cover part of the additional energy needs in the first few months of lactation. Utilization of tissue stores to support lactation, however, is not universal: changes in weight and body composition during lactation are variable, and depend on gestational weight gain, lactation pattern and duration and physical activity level[122].

164. Variation in the energy content of human milk is principally attributable to fluctuation in milk fat concentration which shows complex diurnal, within-feed and between-breast changes. Twenty-four hour milk sampling schemes have been developed which minimally interfere with the secretion of milk flow and capture the diurnal and within-feed variation[128]. The mean gross energy content of human milk in 24-hour representative milk samples of well-nourished women was 2.80 kJ/g or 0.67 kcal/g[43].

165. The biochemical efficiency of converting dietary energy into human milk has been conservatively estimated to be about 80%[43] and the mean milk production rate of women exclusively breastfeeding through 5 months postpartum was 749g/d, obtained by test weighing in mother-infant pairs from both developing and industrialised countries[129]. This value an indicative average for infants of both sexes over the whole six months of exclusive breastfeeding. Correction of the milk production rates for the infant's insensible water loss during a feed (assumed to be equal to 5%) gives a mean milk production rate through 5

months postpartum for exclusively breastfeeding of 807g/d[13]. For partial breastfeeding the variation in milk production is larger, as infant intake is reduced by the proportion derived from other foods. A mean estimate of 492g/day has been made in studies of partially breastfeeding well-nourished women.

166. The average total energy requirements associated with lactation can be estimated by the factorial approach whereby the cost of milk production is added to the energy requirements of non-pregnant women, with an allowance made for energy mobilisation from tissue stores, if replete. In well-nourished women it has been estimated from the rate of weight loss (-0.8kg per month) that 0.72 MJ/day of tissue stores may be utilized to support lactation during the first 6 months postpartum[43].

167. For exclusive breastfeeding through 5 months postpartum, the energy cost of lactation would be 2.8 MJ/day based on a mean milk production of 807 g/day, energy density of milk of 2.8 kJ/g, and energetic efficiency of 0.80. This may be subsidised by energy mobilisation from tissues in the order of 0.72 MJ/day, resulting in a net increment of 2.1 MJ/day over pre-pregnancy energy requirements.

168. The estimated average requirement of breastfed infants in the first 6 months of life is 2.28 MJ/day (see Table 11). If this is met by maternal supply and the energetic efficiency of milk synthesis is assumed to be 0.8, this also equates to a maternal energy cost of about 2.8 MJ/day. Assuming a contribution of 0.72 MJ/day from maternal tissues, the net increment over pre-pregnancy energy requirements is 2.1 MJ/day.

169. The total energy requirements may also be estimated from the sum of TEE plus milk energy output, minus the energy mobilised from tissues. The measurement of TEE by DLW techniques circumvents any assumptions regarding the energetic efficiency of milk synthesis or activity energy expenditure, since they are included in TEE. This approach was taken in four studies between 1 and 6 months postpartum of well-nourished women who exclusively breastfed their infants [123;127;130;131]. Milk energy output averaged 2.15 MJ/day.

170. The US energy DRI for lactation is based on this approach and uses a DLW database of individual energy expenditure measures of lactating women with a pre-pregnancy BMI value of 18.5 up to 25 kg/m^2. The measured TEE, milk energy output and estimated energy mobilisation from tissue stores are used to estimate energy requirements. The recommendation is for an increment of 1380kJ/day (2.1MJ/day - 0.72 MJ/day) for the first 6 months and 1680kJ for the second 6 months of lactation. This is adopted for this report.

171. The FAO/WHO/UNU report[13] employs the factorial approach and recommends an increase in food intake by 2.1MJ/day for the first six months of lactation in well-nourished women. It notes that energy requirements for milk production in the second six months are dependent on rates of milk production that are highly variable among women and populations.

172. Having reviewed the available evidence, SACN agreed that the approach outlined above (paragraph 170) adopted for the US Energy DRI report[20], should be adopted for this report.

Summary of approaches used to derive energy reference values

173. The approaches used to derive energy reference values for infants aged 1-12 months and those during pregnancy and lactation are the same as those reported by FAO/WHO/UNU[13], COMA[1] and, US DRI[20] respectively. For children, adolescents and adults the approaches used and thereby the energy reference values obtained have been revised.

174. Energy reference values for infants were predicted as TEE plus deposited energy accrued during growth. TEE was predicted from a simple equation expressing TEE as a function of weight which was derived from a longitudinal study of TEE measured by DLW[38]. Growth costs were calculated as deposited energy observed during an analysis of the body composition of a population of healthy US infants during normal growth[41].

175. Energy reference values during pregnancy were estimated using a factorial approach based on measured pregnancy-induced increments in BMR plus measured energy deposited as protein and fat. Energy reference values during lactation were derived from measurements of TEE plus estimated milk energy output, allowing for the energy mobilised from tissues of healthy lactating mothers.

176. Energy reference values for children, adolescents and adults were estimated using a factorial approach based on predicted BMR x PAL. BMR is predicted from the Henry prediction equations based on weight, age and gender in children and adolescents and weight, height, age and gender in adults. PAL values are derived from reference data sets assembled from published DLW studies of TEE and used in terms of the median, 25th and 75th centile values of the appropriate reference data set. The reference data set for children and adolescents contained mean values of all identified published studies, and was assembled for boys and girls into defined age groups, 0-3, >3-<10 and 10-18 years. PAL values within these age groups were adjusted by an additional 1% to allow for the energy costs of growth. The reference data set for adults comprised two large population-based studies from a US population with similar demographic and anthropometric characteristics as the current UK population. For children, adolescents and adults the median PAL value for the appropriate age group identified the best estimate of the average level of activity for that group and was used to estimate the EAR. The 25th and 75th centile PAL values were used to estimate energy reference values for groups considered to be less or more active than average. Estimates are also given of the probable additional energy needs associated with changes in habitual activity involving specific types of activity such as increased walking, running and participation in sport or high-level training regimes. The likely increases in PAL associated with such changes in lifestyle are given. For healthy mobile older adults energy requirements are unlikely to differ substantially from younger adults so that requirements can be described in the same way. In advanced age with reduced mobility, however, activity and energy requirements fall so that lower PAL values are appropriate.

177. Any energy reference values need to be viewed in light of the serious concerns regarding the assumptions underpinning the DLW method and prediction of BMR values, and the representativeness of study participants. For example, younger adults aged 18-30 years are particularly under-represented in the adult data set.

4 Energy reference values

Infants, children and adolescents

Infants aged 1-12 months

178. As discussed in the previous chapter, the EARs for infants are derived on a basis similar to that employed by the FAO/WHO/UNU Expert Consultation. They have been calculated from TEE (measured by the DLW method) plus the energy needs for growth. The WHO Growth Standard weights[115] have been used to derive EARs for both breastfed and breast milk substitute-fed infants, as recommended by the SACN[77]. These standards describe the growth pattern of healthy infants living in non-deprived circumstances who were exclusively or predominantly breastfed for at least 4 months. Since this pattern of growth is associated with favourable health outcomes it is considered applicable to breast milk substitute-fed infants as an indicator of optimal growth.

Table 11. Draft EAR values for breastfed infants 1–12 months of age

Age (months)	Weight (kg)[a]	Weight velocity (g/day)[b]	Total energy expenditure (kJ/day)	Energy deposition (kJ/g)	Energy deposition (kJ/day)	EAR (kJ/day)	Energy requirement (kJ/kg per day)
Boys							
1	4.47	37.1	1099	25.1	931	2031	454
2	5.56	35.8	1522	25.1	899	2421	435
3	6.37	26.6	1837	25.1	668	2504	393
4	7.00	20.7	2081	11.6	240	2321	332
5	7.51	16.8	2279	11.6	195	2474	329
6	7.93	13.8	2442	11.6	160	2602	328
7	8.30	12.2	2585	6.2	76	2661	321
8	8.61	10.2	2706	6.2	63	2769	322
9	8.90	9.5	2818	6.2	59	2877	323
10	9.16	8.5	2919	11.4	97	3016	329
11	9.41	8.2	3016	11.4	93	3110	330
12	9.65	7.9	3109	11.4	90	3199	332
Girls							
1	4.19	31.6	991	26.2	828	1819	434
2	5.13	30.9	1355	26.2	810	2165	422
3	5.84	23.3	1631	26.2	610	2241	384
4	6.42	19.1	1856	15.6	298	2154	336
5	6.90	15.8	2042	15.6	246	2289	332
6	7.30	13.1	2197	15.6	204	2402	329
7	7.64	11.2	2329	7.4	83	2412	316
8	7.95	10.2	2450	7.4	75	2525	318
9	8.22	8.9	2554	7.4	66	2620	319
10	8.48	8.5	2655	9.8	83	2739	323
11	8.72	7.9	2748	9.8	77	2826	324
12	8.95	7.6	2838	9.8	74	2912	325

[a] 50th percentile weight for age of the WHO Growth Standards [115]
[b] 50th percentile weight increment of the WHO Growth Standards [115]

Table 12. Draft EAR values for breast milk substitute-fed infants 0–12 months of age

Age (months)	Weight (kg)[a]	Weight velocity (g/day)[b]	Total energy expenditure (kJ/day)	Energy deposition (kJ/g)	Energy deposition (kJ/day)	EAR (kJ/day)	Energy requirement (kJ/kg per day)
Boys							
1	4.47	37.1	1425	25.1	931	2356	527
2	5.56	35.8	1802	25.1	899	2700	486
3	6.37	26.6	2082	25.1	668	2750	432
4	7.00	20.7	2300	11.6	240	2540	363
5	7.51	16.8	2476	11.6	195	2671	356
6	7.93	13.8	2622	11.6	160	2782	351
7	8.30	12.2	2750	6.2	76	2825	340
8	8.61	10.2	2857	6.2	63	2920	339
9	8.90	9.5	2957	6.2	59	3016	339
10	9.16	8.5	3047	11.4	97	3144	343
11	9.41	8.2	3134	11.4	93	3227	343
12	9.65	7.9	3217	11.4	90	3307	343
Girls							
1	4.19	31.6	1328	26.2	828	2156	514
2	5.13	30.9	1653	26.2	810	2463	480
3	5.84	23.3	1899	26.2	610	2509	430
4	6.42	19.1	2099	15.6	298	2397	373
5	6.90	15.8	2265	15.6	246	2512	364
6	7.30	13.1	2404	15.6	204	2608	357
7	7.64	11.2	2521	7.4	83	2604	341
8	7.95	10.2	2629	7.4	75	2704	340
9	8.22	8.9	2722	7.4	66	2788	339
10	8.48	8.5	2812	9.8	83	2895	341
11	8.72	7.9	2895	9.8	77	2973	341
12	8.95	7.6	2975	9.8	74	3049	341

[a] 50th percentile weight for age of the WHO Growth Standards [115]
[b] 50th percentile weight increment of the WHO Growth Standards [115]

Children and adolescents aged 1-18 years

179. The energy reference values for this age group were derived using a factorial model BMR x PAL, with PAL adjusted for growth by a 1% increase. Growth- adjusted PAL values are the 25th, median and 75th centiles of the PAL distributions for each age group (1-3, >3-<10 and 10-18). The Estimated Average Requirement (EAR) is indicated by the value calculated by the median PAL whilst requirements for less active or more active children are calculated from the 25th and 75th centiles.

Table 13. Draft EAR values for energy based on mean weights from the WHO growth standards (ages 1 to 2) and the UK1990 reference (for over 2 years of age) for children and adolescents aged 1-18years

Age (years)	Boys		Girls		PAL (boys and girls)			Energy requirements MJ/d					
								Boys			Girls		
	Weight kg	BMR MJ/d	Weight kg	BMR MJ/d	Q25	Median	Q75	less active	EAR	more active	less active	EAR	more active
1	11.0	2.66	10.3	2.44	1.36	**1.40**	1.45	3.6	**3.7**	3.9	3.3	**3.4**	3.5
2	12.4	3.02	12.1	2.88	1.36	**1.40**	1.45	4.1	**4.2**	4.4	3.9	**4.0**	4.2
3	14.7	3.61	14.2	3.40	1.36	**1.40**	1.45	4.9	**5.1**	5.2	4.6	**4.8**	4.9
4	16.6	3.71	16.3	3.49	1.43	**1.58**	1.70	5.3	**5.9**	6.3	5.0	**5.5**	6.0
5	18.6	3.89	18.2	3.65	1.43	**1.58**	1.70	5.6	**6.2**	6.6	5.2	**5.8**	6.2
6	21.0	4.12	21.0	3.89	1.43	**1.58**	1.70	5.9	**6.5**	7.0	5.6	**6.2**	6.6
7	23.0	4.31	23.0	4.06	1.43	**1.58**	1.70	6.2	**6.8**	7.3	5.8	**6.4**	6.9
8	26.0	4.59	26.0	4.31	1.43	**1.58**	1.70	6.6	**7.3**	7.8	6.2	**6.8**	7.3
9	29.0	4.87	29.0	4.56	1.43	**1.58**	1.70	7.0	**7.7**	8.3	6.5	**7.2**	7.8
10	31.5	4.98	32.0	4.74	1.68	**1.75**	1.86	8.3	**8.7**	9.3	8.0	**8.3**	8.8
11	34.5	5.08	35.9	4.85	1.68	**1.75**	1.86	8.5	**8.9**	9.5	8.1	**8.5**	9.0
12	38.0	5.35	40.0	5.04	1.68	**1.75**	1.86	9.0	**9.4**	10.0	8.5	**8.8**	9.4
13	43.0	5.74	46.0	5.32	1.68	**1.75**	1.86	9.6	**10.0**	10.7	8.9	**9.3**	9.9
14	49.0	6.20	51.0	5.55	1.68	**1.75**	1.86	10.4	**10.8**	11.6	9.3	**9.7**	10.4
15	55.5	6.70	53.0	5.64	1.68	**1.75**	1.86	11.2	**11.7**	12.5	9.5	**9.9**	10.5
16	60.2	7.06	55.3	5.75	1.68	**1.75**	1.86	11.8	**12.4**	13.2	9.6	**10.1**	10.7
17	64.0	7.35	57.0	5.83	1.68	**1.75**	1.86	12.3	**12.9**	13.7	9.8	**10.2**	10.9
18	66.2	7.52	57.2	5.84	1.68	**1.75**	1.86	12.6	**13.2**	14.0	9.8	**10.2**	10.9

Adults

180. Energy reference values for adults are derived by the factorial calculation of TEE from BMR x PAL. BMR values are calculated from the Henry[57] equations (see Appendix 3) using heights and weights of the UK population indicated by the NDNS of adults aged 19-64 years, 2000/1[7] (see Table 14). The heights and weights shown are for men and women for the observed range of heights (mean, lower and upper 2.5th centile) within BMI values of 20, 22.5 and 25kg/m2. BMR values calculated from these are shown in Table 15.

Table14. Weights for UK adults for the BMI range 20-25 kg/m²*

		Men	Weight (kg) at:			Women	Weight (kg) at:		
Age (yrs)	Height	cm	BMI 20	BMI 22.5	BMI 25	cm	BMI 20	BMI 22.5	BMI 25
19-24	Mean	177	62.7	70.5	78.3	163	53.1	59.8	66.4
	lower 2.5 centile	163	53.1	59.8	66.4	150	45.0	50.6	56.3
	higher 2.5 centile	190	72.2	81.2	90.3	175	61.3	68.9	76.6
25-34	Mean	177	62.7	70.5	78.3	162	52.5	59.0	65.6
	lower 2.5 %ile	165	54.5	61.3	68.1	148	43.8	49.3	54.8
	higher 2.5 %ile	188	70.7	79.5	88.4	172	59.2	66.6	74.0
35-49	Mean	176	62.0	69.7	77.4	162	52.5	59.0	65.6
	lower 2.5 %ile	161	51.8	58.3	64.8	151	45.6	51.3	57.0
	higher 2.5 %ile	190	72.2	81.2	90.3	175	61.3	68.9	76.6
50-64	Mean	175	61.3	68.9	76.6	160	51.2	57.6	64.0
	lower 2.5 %ile	162	52.5	59.0	65.6	148	43.8	49.3	54.8
	higher 2.5 %ile	188	70.7	79.5	88.4	173	59.9	67.3	74.8
65-74	Mean	172	59.2	66.6	74.0	159	50.6	56.9	63.2
75+	Mean	169	57.1	64.3	71.4	155	48.1	54.1	60.1

*derived from current UK heights listed for each BMI value

Table15. BMR values for UK adults for the BMI range 20-25 kg/m²*

		Men BMR MJ/day			Women BMR MJ/day		
Age (yrs)	Height	BMI 20	BMI 22.5	BMI 25	BMI 20	BMI 22.5	BMI 25
19-24	Mean	6.55	7.02	7.49	5.31	5.60	5.89
	lower 2.5 centile	5.80	6.20	6.59	4.62	4.87	5.11
	higher 2.5 centile	7.29	7.84	8.38	5.97	6.30	6.63
25-34	Mean	6.55	7.02	7.49	5.26	5.54	5.82
	lower 2.5 %ile	5.90	6.31	6.72	4.52	4.76	4.99
	higher 2.5 %ile	7.18	7.71	8.24	5.80	6.12	6.44
35-49	Mean	6.35	6.72	7.09	5.15	5.37	5.60
	lower 2.5 %ile	5.53	5.84	6.15	4.68	4.88	5.07
	higher 2.5 %ile	7.16	7.59	8.02	5.72	5.98	6.24
50-64	Mean	6.30	6.66	7.03	5.06	5.28	5.50
	lower 2.5 %ile	5.59	5.90	6.21	4.56	4.74	4.93
	higher 2.5 %ile	7.04	7.46	7.88	5.63	5.89	6.14
65-74	Mean	5.65	6.00	6.35	4.64	4.87	5.09
75+	Mean	5.48	5.82	6.16	4.48	4.70	4.91

*derived from weights and heights shown in Table 24 from the Henry prediction equations (see Appendix 3)

181. Tables 16 and 17 show the draft EARs for men and women respectively, with weights and heights representing the mean values for a BMI of 22.5 (see Table 14). PAL is independent of gender and the change with age is too small to have any significant influence so that a single set of PAL values calculated as median, 25th and 75th centile boundaries of the reference population is used (see Appendix 10). The EAR is indicated by the value calculated by the median PAL which is the assumed population level, in the absence of other information on activity. Requirements for population groups thought to be less active or

more active than average are calculated from the 25th and 75th quartile boundary PAL values respectively.

Table 16. Draft EAR values for energy for groups of men at various ages, weights and physical activity levels[1], at mean height for age and a BMI of 22.5

			Energy requirements MJ/d		
Age range	Mean height cm	Weight[2] kg	less active[3]	EAR[4]	More active[5]
19-24	177	70.5	10.5	**11.4**	12.5
25-34	177	70.5	10.5	**11.4**	12.5
35-49	176	69.7	10.0	**11.0**	12.0
50-64	175	68.9	9.9	**10.9**	11.9
65-74	172	66.6	8.9	**9.8**	10.7
75+	169	64.3	8.7	**9.5**	10.4

1. Derived as BMR x PAL with BMR values from Table 24 for the BMI range 20-25 kg/m2
2. at BMI= 22.5
3. 25th centile PAL =1.49
4. Median PAL= 1.63
5. 75th centile PAL=1.78

Table 17. Draft EAR values for energy for groups of women at various ages, weights and physical activity levels[1], at mean height for age and a BMI of 22.5

			Energy requirements MJ/d		
Age range	Mean height cm	Weight[2] kg	less active[3]	EAR[4]	More active[5]
19-24	163	59.8	8.3	**9.1**	10.0
25-34	162	59.0	8.3	**9.0**	9.9
35-49	162	59.0	8.0	**8.8**	9.6
50-64	160	57.6	7.9	**8.6**	9.4
65-74	159	56.9	7.3	**7.9**	8.7
75+	155	54.1	7.0	**7.7**	8.4

1. Derived as BMR x PAL with BMR values from Table 24
2. at BMI= 22.5
3. 25th centile PAL =1.49
4. Median PAL= 1.63
5. 75th centile PAL=1.78

Energy reference values for extreme old age

182. As indicated above the energy reference values for older adults are unlikely to differ from younger adults whilst general health and mobility are maintained. However, for the extreme elderly as activities become limited, energy expenditure and the consequent requirement is likely to fall to within the less active range (PAL = 25th centile=1.49) or lower, with PAL values as low as 1.38 having being observed in some otherwise healthy subjects in the final years of life.

Energy reference values for pregnancy

183. The Committee notes that energy reference values for pregnancy estimated by the factorial method exceed energy intakes observed in well nourished populations with average birth weight in the healthy range. Consequently, the Committee sees no reason to amend the increment of 0.8 MJ/d in the last trimester previously recommended by COMA. Women entering pregnancy who are overweight may not require this increment but current data are insufficient to make a recommendation regarding this group. This approach was also taken in the US DRI report[20].

Energy reference values for lactation

184. Factorial calculation suggests that women with a healthy pre-pregnancy weight (BMI 18.5-24.9) who exclusively breastfeed their infants throughout the first six months require an increment of 2.1 MJ/day above the pre-pregnant EAR. However the factor of 0.8 applied to adjust for efficiency of conversion of maternal energy intake to milk is insecure and likely to be a conservative estimate. This could explain why the factorial estimate is appreciably greater than that measured in DLW experiments. The Committee recommends adoption of the US Energy DRI[20], based on DLW measurements, of 1.4 MJ /d in the first 6 months and 1.7 in the second six months of lactation.

Comparisons with reference values for energy in other reports

185. The energy reference values detailed in this report are different from those calculated by COMA in 1991, being broadly higher for newborn infants (10-14%), adolescents, especially girls (14-15%), and adults and lower for other infants (7-18%) and preadolescent children (1-16%). These differences are discussed in detail in Appendix 11. In all cases in this report, energy reference values have been calculated from rates of energy expenditure assessed by the DLW method. This data has been used either directly as a measure of TEE for infants or, in all other cases, to identify suitable PAL values which have been employed within a factorial calculation as PAL x BMR, with BMR estimated by the Henry prediction equations. The way such calculations have been made in previous reports (COMA[1], FAO/WHO/UNU[13] and US DRI report[20]), is discussed in Appendix 2 paragraphs 259-266, and the use of the Henry BMR prediction equations is discussed in Appendix 3.

186. Insufficient DLW data was available to COMA[1] to enable energy reference values to be defined for any age group although such data that was available was used to reinforce energy

intake data for infants and young children. Energy intake data alone was used by COMA[1] for all preadolescent children. COMA[1] adopted the factorial approach of predicting TEE from BMR x PAL for children aged 10-18, assigning PAL values of 1.56 for boys and 1.48 for girls with small additions made for growth costs. The gender difference was based on the view that girls exhibited lower levels of physical activity than boys. No evidence for this has been identified in this report and a median PAL value of 1.75 has been used for boys and girls aged 10-18, which includes the growth costs. This explains the higher energy reference values for teenagers, especially girls, in this report.

187. For adults, although COMA[1] discussed a matrix of PAL values varying by occupational and leisure activities from 1.4-1.9 for men and 1.4-1.7 for women, on the basis that judgements could be made about lifestyles of population groups, it was recommended that a PAL value of 1.4 should be used in the absence of information on activity. This value, which is lower than both the 25th centile and median PAL (1.49 and 1.63 respectively for both men and women), has been widely employed since and has been the basis of the guideline daily amounts (GDAs) for energy used in food labelling[132].

188. The higher reference values for adults in this report reflect a better database of published DLW data than was available for any previous report and a better understanding of the extent and nature of the variation in TEE within populations and lifestyle groups. This has clearly indicated the impracticality of predicting lifestyle-dependent PAL values other than as distributions within reference populations i.e. 25th centile (less active), 1.49; median (typical activity), 1.63; and 75th centile (more active), 1.78, with simple recommendations for the likely influence of changes in activity on PAL values. In fact this approach, adopted here for children and adults, is similar in principle to that recommended for children and adolescents by FAO/WHO/UNU[13]: i.e. identifying average PAL values from the DLW data with a ±15% variation for more or less active children. However, here, PAL values for broad age ranges, (1-3, >3-<10, 10-18) have been aggregated, whereas FAO/WHO/UNU[13] predict PAL values for each year of age by regression analysis of the DLW data.

189. The energy reference value identified here for pregnancy, a single daily increment of 0.8 MJ/d in the last trimester, is the same as previously recommended by COMA[1], but considerably lower than that recommended by either FAO/WHO/UNU[13] (1.5MJ/day during the second trimester and 2.0MJ/day during the third trimester) or in the US DRI report[20] (1.43MJ/day during the second trimester and 1.9MJ/day during the third trimester, see paragraphs 158-161). As argued above (paragraph 162) there are cogent arguments for avoiding excessive weight, especially fat gain, in pregnancy and evidence for adaptive changes in energy expenditure which reduce the need for additional food energy intake. Although such arguments were not taken into account in the previous reports, SACN considered them to be valid and sufficiently important to guide its recommendation in this report.

190. The energy reference value identified here for lactation, an increment of 1.38MJ/day for the first 6 months and 1.68MJ for the second 6 months of lactation, is the same as previously recommended in the US DRI report[20], but considerably lower than that recommended by either COMA[1], an increment of 1.9-2.4MJ/day for the first 6 months and 1.0-2.3MJ for the second 6 months of lactation, or by FAO/WHO/UNU[13] (2.1MJ/day for the first 6 months with no recommendation for any subsequent breastfeeding). In all cases the values derive from estimated milk energy contents less the energy mobilised from maternal stores, with different calculations for the magnitude of these two components. The higher value

recommended by FAO/WHO/UNU[13] is mainly because of the inclusion of a scaling factor for milk energy content of +25% to take into account an assumed inefficiency of dietary energy utilization to provide for milk energy. Because such energy costs would appear as increased TEE in lactating women and because such increases are not observed in practice, the inclusion of such as scaling factor is arguably unwarranted.

5 Summary and conclusions

191. The Dietary Reference Values (DRV) for food energy provide a best estimate of the energy needs of the UK population and population subgroups and present criteria against which to judge the adequacy of their food energy intakes. The National Diet and Nutrition Survey (NDNS) series has consistently found reported average energy intakes to be below the Estimated Average Requirement (EAR[2]) set by COMA in 1991[1]. In reality, average habitual energy intakes are more likely to exceed energy needs, as evidenced by the increasing proportions of people classified as overweight and obese in the UK. Underreporting of food intake may explain this paradox as it is known to partly account for a commonly reported discrepancy between measured *total energy expenditure* (TEE) and the apparent low energy intakes in NDNS and other dietary surveys. These observations, the accumulating evidence base on TEE in a wide variety of population groups, and the publication of the FAO/WHO/UNU Human Energy Requirements report [13] led the Food Standards Agency and Department of Health to request a re-evaluation of the DRVs for food energy by the Scientific Advisory Committee on Nutrition (SACN).

192. Measurements of TEE together with estimates of deposited energy provide the basis for estimating energy reference values. In the absence of growth, an individual's TEE is the sum of daily energy used to maintain *basal metabolic rate* (BMR; metabolism at rest), energy expended in physical activity, and thermogenesis deriving mainly from food intake. TEE can be expressed as a multiple of BMR, the *physical activity level* (PAL); hence TEE or EAR is equal to BMR x PAL. BMR is predictable as a function of age, weight and gender, while PAL, which is a descriptor of lifestyle and/or behaviour as determinants of energy expenditure, is independent of these factors, at least as a first approximation. Thus for any PAL value, TEE can be predicted for any group from estimates of the BMR. During growth, pregnancy and lactation the energy cost of tissue deposited also needs to be taken into account.

193. The most accurate practical means of measuring TEE in free-living individuals integrated over days and weeks is the *doubly labelled water* (DLW) method. In this method TEE of individuals is computed from estimates of CO_2 production. These are calculated from the loss of the isotopes ^{18}O and ^{2}H from the body over time following the administration of a standard dose. The computation relies on a series of assumptions (e.g. about water losses and metabolic fuel use) the validity of which varies between and within individuals, but the limits of such variability are known and considered generally acceptable for the purpose of estimating EARs.

194. In recent years, EAR values for populations have been estimated from DLW-derived measures of TEE in reference populations together with estimates of deposited energy. There are two basic approaches: TEE can be modelled against different characteristics of the reference population (e.g. age, weight) using regression equations and the regression equations can then be used to predict TEE and EAR values for population groups.

[2] The DRV for dietary energy has usually been defined as the mean energy requirement, or Estimated Average Requirement (EAR), of those who constitute the defined group.

Alternatively measured TEE values and measured or predicted BMR values from the reference populations can be used to estimate PAL values. These PAL values can then be used to derive TEE and EAR values for population groups on the basis of their predicted BMR values. This is a *factorial* approach to setting EARs. Both approaches are limited by the validity of the DLW method and to a larger extent by the representativeness of the study participants compared with those groups to whom the EAR will be applied. For example, in the UK there has recently been concern that, despite random recruitment, those who take part in NDNS DLW sub-studies tend to be more physically active than those who do not: i.e. the "healthy volunteer effect". It is not known whether this is the case in the larger DLW data sets used in this report.

195. As no large population-based UK studies of any age group have been conducted using DLW, SACN utilized a variety of other data sources (reference populations) to derive the proposed EAR values. Those identified as being the most likely to be representative of the UK population were as follows:

- For infants, a longitudinal study of healthy American infants comprising similar numbers of breast fed and breast milk substitute fed infants (n=76 individuals[38])
- For children and adolescents, a compilation of all identified mean study values for specific ages for boys and girls (n=170 mean study values) (Appendix 9)
- For adults, two studies[61;62] of adult urban populations in the US, with similar demographic and anthropometric characteristics as the overall current UK population (n = 890 individuals; Appendix 10)
- For older adults, no specific representative data set has been identified (see paragraphs 137-139 for discussion).

196. The limitations of these data sets (reference populations) for deriving estimated EARs for the UK population include the small numbers of participants in the infant and child cohorts and the lack of younger adults aged 18-30 years in the larger adult data set.

197. The application of these data sets to the determination of EAR values is as follows:

- *For infants from birth to 12 months*, FAO/WHO/UNU energy requirement recommendations[13;110] were modified by the application of infant growth data from the WHO Multicentre Growth Reference Study[115]. In comparison with the previous COMA values[1], the proposed EAR for infants aged 1-12 months (in kJ/kg per day) are similar for the first 3 months, but are lower between 6 and 12 months, e.g. 340 kJ/kg per day compared with about 400 kJ/kg per day.
- *For pregnancy and lactation*, the COMA DRV[1] and US DRIs[20] have been used respectively, and reference values given as incremental energy requirements for pregnancy and lactation.

- *For children, adolescents and adults*, proposed reference values have been determined using a factorial method of predicting TEE from BMR x PAL. In 1991 it was assumed by COMA[1] that PAL could be predicted for population groups from knowledge of the pattern and extent of daily activities. However, evidence suggests that even if such information is available, prediction of PAL cannot be done with the accuracy previously assumed. For this reason a different approach has been adopted here. The distribution of PAL values within the reference population has been used to indicate the overall average value for PAL as well as the extent to which it is lower or higher for less or more active population groups. Thus, three PAL values are identified for age bands of children and adolescents and for adults, the median, 25th and 75th centile. These represent best estimates of the whole population and of those who are less and more active than usual. In addition, estimates of the likely increase in PAL associated with changes in activity levels to varying degrees are given.

198. COMA estimated average PAL values to be 1.4[1]; this relatively low PAL was seen to be in keeping with the sedentary life style of the UK population. An analysis of the range and distribution of PAL values (described in Appendix 2) shows that average PAL values were likely to have been underestimated by COMA. A PAL value of 1.4 is lower than the values observed for 90% of the subjects in the reference adult population examined for this report (see Appendix 10) which has similar levels of overweight and obesity (approximately 60%) as in the current UK population. The likely reason for this discrepancy was under-appreciation of the influence of routine activities of daily living on energy expenditure. Median PAL values identified for teenagers and adults, 1.75 and 1.63 respectively, are each higher than the previously assumed population PAL value of 1.4. The underestimate of PAL by COMA led to EAR values also being underestimated.

199. The proposed EAR values in this report are therefore generally higher for teenage boys (up to 9%) and girls (up to 15%), and for all adults by up to 16%. The factorial model was not previously used for pre-adolescent children and these new values represent lower EAR values (by between 1-18%) for infants and children from 3 months up to the age of 10 years, (see Appendix 11).

- *For older adults,* evidence indicates EAR values estimated for adults should also be applied whilst general health and mobility are maintained (see paragraphs 137-139). In advanced old age with reduced mobility EARs are likely to decrease as PAL declines.

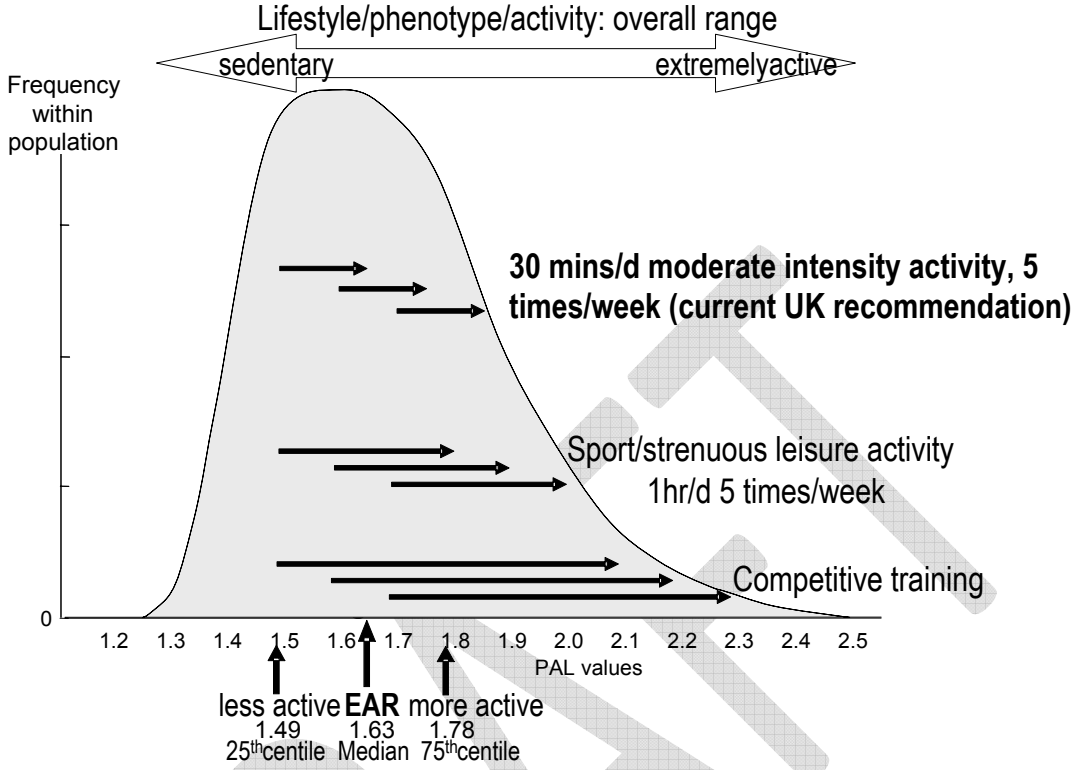
200. In this report, revised PAL values have had the most significant impact on the proposed EARs, being up to 16% higher. The estimated BMR values are slightly lower than those used by COMA[1] as a result of the Henry prediction equations being used in place of those of Schofield but these differences are minor compared with the changes to PAL values.

201. The reference population identified for estimation of the adult energy reference values comprises predominantly overweight and obese individuals (mean BMI=28: range 18-43). This population was deemed to be appropriate because the distribution of BMI was similar to that in the current UK population. No relationship was observed between the distribution of BMI and activity levels (PAL values) within this population group. The risk of overweight and obesity was therefore independent of measured TEE (see Appendix 10, Tables 42 and 43); these data did not show that low or high PAL values were more or less likely to be associated with a positive energy imbalance. This is not to underestimate the importance of proposals for increased physical activity for the general health of the population, referred to

in paragraph 207 below.

202. The following general statement describes the energy requirements of adults, with the principle illustrated by Figure 4. It should, however, be viewed with caution given the limitations of the data (outlined in paragraph 203). The energy intake reference value for the current adult population balances an energy expenditure on average of about 1.63 x BMR, with BMR varying with bodyweight, age and gender; this value can be assumed to be maintained in old age as long as subjects remain mobile and independent. Rates of energy expenditure and consequent requirements vary markedly between individuals, mainly as a result of lifestyle, but also through individual behavioural characteristics. Within the population the overall range is normally between about 1.38-2.5 x BMR; PAL values can fall as low as 1.27x BMR and may exceed 2.5, but such low and high values are not thought to be sustainable. Although it is inherently difficult to predict rates of energy expenditure for individuals or population groups, for those judged to be either less or more active than average, representative PAL values of 1.49 and 1.78 are appropriate. Individuals may require less or more than the reference values, but individual appetite generally helps match intakes with expenditure. For individuals leading lives with little physical activity, but maintaining bodyweight, energy expenditure and hence requirements could be increased by about 0.15 x BMR by 30 minutes of moderate intensity exercise on five days of the week (as currently recommended by UK health departments), 0.2 x BMR by a brisk walk of 1 hour/day or 0.3 x BMR by participation in significant amounts of sport or strenuous leisure activity for 60 minutes, 5 times per week. Individuals entering training for competitive aerobic sporting activities may increase TEE by 0.6 x BMR. For very old people in whom activities become limited, energy expenditure and requirement is likely to be at the low end of the physiological range.

Figure 4. Schematic representation of energy expenditure and consequent energy requirements of men and women as a function of the physical activity (PAL) value [a].



[a]The distribution of PAL values is that of the reference population discussed in Appendix 10. The likely increases in PAL and consequent energy needs shown for various activities are those identified in Table 10 and include the current recommendations from UK health departments (30 minutes of moderate intensity exercise on five days per week, PAL increase of 0.15). These increases are shown as they would affect individuals with initial PAL values of 1.5, 1.6 and 1.7. However as explained in Table 22, Appendix 2, the actual increase in PAL associated with a specific activity will vary to a small extent with the initial PAL, i.e. with the intensity of the activity replaced. This means that the actual increases will be slightly less than the values shown especially for subjects with high initial PAL values.

203. As described above, based on the best available evidence a case can be made that the EARs for teenagers and adults should be increased due to COMA's[1] previous underestimation of habitual physical activity and hence TEE. The proposed EAR estimates are based upon a much larger body of evidence than was available in 1991. However, it is important to note the insecurities in: the data sets (reference population) from which they are derived, including the paucity of data for younger adults aged 18-30 years; the methods used to calculate EAR, PAL and BMR values from TEE; and in the measurement of TEE itself (see Appendix 1).

204. The approaches used previously by COMA and in this report have produced reference values that 'band' population subgroups according to the mean EAR value for that group. This approach results in the reference value being too low for some people and too high for others. Caution is therefore required when applying these EAR values to groups since a mismatch between energy intake and energy expenditure (unlike most nutrients) has major

public health implications; a proportion of any group would gain weight inappropriately while others would become undernourished if everyone received the same energy intake.

205. The high prevalence of overweight and obesity in the UK population shows that, for the majority of people, energy intakes are in excess of energy requirements. It is important that the proposed EAR values are not used to signal or encourage an increase in energy intake of the population as a whole; this would increase the prevalence and magnitude of overweight and obesity in the absence of a corresponding increase in energy expenditure.

206. On the basis of current evidence regarding the impact of both diet and physical activity on the risk of weight gain (see Appendices 7 and 8), it is not possible to define the extent or nature of these two influences on weight gain in any detail. Nevertheless, it is clear that both physical activity and a balanced diet have important roles in maintaining good health. Weight gain is only possible when energy is consumed in excess of requirements, so it is important that individuals are aware of their energy intakes relative to their energy expenditure. Higher physical activity energy expenditures balanced by a higher energy intake in the form of a nutritionally balanced diet could be expected to yield health benefits, by both increasing fitness and overall nutrient intakes.

207. Finally, it is important to recognise that for teenagers and adults the proposed, mainly higher EAR estimates in this report do not indicate increasing energy needs of these groups as a result of increasing activity. Instead, they represent a closer estimation of their energy needs at current activity levels. Available evidence, although limited, shows that increasing physical activity reduces the risk of becoming obese. SACN fully endorses current public health recommendations from the UK health departments regarding physical activity; that adults should aim to achieve at least 30 minutes of moderate intensity activity on five or more days of the week while children and young people should aim for 60 minutes every day. If the UK population respond to such recommendations, PAL values and consequent energy reference values would increase: i.e. closer to the current 75th centile identified for the "more active" population and further increases in balancing energy intakes would be appropriate.

RECOMMENDATIONS WILL BE MADE FOLLOWING THE SCIENTIFIC CONSULTATION.

Acknowledgements

The Committee would like to thank the principle investigators from the OPEN and Beltsville studies for providing data for this report.

Glossary

Accelerometry	A non-calorimetric method of assessing free living energy expenditure by monitoring activity and movement.
Adenosine triphosphate (ATP)	The cofactor that acts as an intermediate between catabolic, anabolic and energy expenditure reactions
Adipose tissue	Body fat storage tissue. Distributed under the skin and around body organs. Composed of cells that synthesise and store fat, releasing it for metabolism in fasting.
Anthropometry	Body measurements made non-invasively to assess body composition, physiological development and nutritional status.
Basal metabolic rate (BMR)	Rate at which the body uses energy when it is at complete rest, when food and physical activity have minimal influence on metabolism.
Body Mass Index (BMI)	An index of weight adequacy and obesity of older children and adults. Weight in kilograms divided by the square of height in meters.
Dietary Reference Value (DRV)	A term used to define the various expressions of estimated dietary requirements in individuals and population groups. DRVs comprise of 3 levels of intake Lower Reference Nutrient Intake, Reference Nutrient Intake and Estimated Average Requirement (see glossary entry).
Direct calorimetry	Calorimetry is a method of energy expenditure measurement. Direct calorimetry is a measure of heat output from the body, as an index of energy expenditure.
Doubly labelled water (DLW)	The stable (non radioactive) isotope method for estimating energy expenditure in free living individuals over extended periods up to several weeks. Subjects consume water containing isotopes hydrogen ($^{2}H_2$) and oxygen (^{18}O).
Energy balance	The difference between metabolizable energy intake and total energy expenditure. A neutral energy balance occurs when energy intake is equal to energy expenditure.
Estimated Average Requirement (EAR)	This is an estimate of the average requirement for energy or a nutrient. It is the appropriate level by which adequacy of intakes of populations, but not individuals, can be judged.
Post exercise O_2 consumption (EPOC)	Excess O_2 consumption following exercise. Small increase in energy expenditure following exercise which persists for some

	time after the exertion itself has been completed.
Fat Mass	The component of body composition made up of fat.
Fat Free Mass (FFM)	The non fat component of body composition comprising muscle, bone, skin and organs.
Food frequency questionnaire	A method for assessing past dietary intake. A questionnaire asking the frequency of consumption of foods over a day/week/month etc.
Gross Energy (GE)	The total maximum amount of energy contained within food, determined by measuring the heat released after complete combustion to carbon dioxide and water.
Glycogen	The storage carbohydrate in the liver and muscles. A branched polymer of glucose units.
Heart rate monitoring (HRM)	A method for measuring free living energy expenditure. Heart rate is monitored minute by minute throughout the day using portable meters. The energy expenditure at a given heart rate can be estimated using an individual linear regression line of the relationship between oxygen consumption and heart rate.
Heat Increment of Feeding	Increased heat production following consumption on food.
Homeostasis	The control of key components, (such as temperature and blood constituent concentrations) to ensure consistency and physiological normalisation.
Hyperglycaemia	Elevated plasma concentration of glucose, caused by failure of the normal hormonal mechanisms of blood glucose control.
Hypoglycaemia	Abnormally low concentration of plasma glucose.
Indirect calorimetry	Calorimetry is the measurement of energy expenditure. Indirect calorimetry is the most commonly used approach. It is the calculation of energy expenditure by the measurement of oxygen consumption and carbon dioxide production.
Insulin resistance	Reduction in the biological activity of insulin sensitive peripheral tissues, which results in reduced disposal glucose from plasma for any given concentration of insulin.
kilojoule (kJ) / megajoule (MJ)	Units used to measure the energy value of food, 1kJ=1000 joules, 1MJ = 1 million joules
Lipolysis	The breakdown of fat molecules e.g. triglycerides.
Lower Reference Nutrient Intake (LRNI)	Two notional standard deviations below the mean (or EAR). Represents the lower limit of the distribution of nutrient requirements

	within a population. For an individual, an intake below this level is almost certainly inadequate. For populations this intake should not be used to define deficiency since it will markedly overestimate deficiency prevalence.
Metabolizable energy (ME)	The energy contained within food that is available to human metabolism.
Metabolic equivalent (MET)	Unit of measurement of heat production by the body; 1 MET ≡ 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$
Net Metabolizable energy (NME)	The actual ATP producing capacity of foods.
Non exercise activity thermogenesis (NEAT)	Increase in energy expenditure due to involuntary activity/behaviours such as fidgeting, muscle tone, posture maintenance.
Physical Activity Level (PAL)	Daily total energy expenditure (TEE) expressed as multiple of Basal metabolic rate (BMR). It is calculated as TEE divided by BMR.
Physical activity-related energy expenditure (PAEE)	The component of energy expenditure related to physical activity.
Physical Activity Ratio (PAR)	Energy cost of different physical activities per unit of time expressed as a multiple of BMR.
Reference Nutrient Intake (RNI)	Two notional standard deviations above the mean (or EAR). Represents the upper limit of the distribution of nutrient requirements within a population. For an individual, an intake above this level is almost certainly adequate. For populations this intake should not be used to define adequacy since it will usually be less than the intake sufficient to meet the nutritional needs of most of the population.
Resting metabolic rate (RMR)	Rate at which the body uses energy when it is at rest. Sometimes used interchangeably with BMR but RMR is not measured at the standardised metabolic state and can include TEF and EPOC.
Thermic Effect of Food (TEF)	The increase in heat production by the body after eating, due to both the metabolic energy cost of ingestion, digestion and the energy cost of forming tissue reserves of fat, glycogen and protein.
Total Energy Expenditure (TEE)	The sum of all the energy expended by an individual over the course of one day. It includes BMR, PAEE and TEF and represents the average amount of energy spent in a typical day.
US DRI (dietary reference intakes)	US term for dietary reference values (includes the terms average requirement, Recommended Daily Amount and tolerable upper levels for supplements)

Glossary of Statistical terms

Linear Regression Analysis:

- Simple linear regression - A statistical method that attempts to explain the relationship between a dependent variable and a single independent variables by fitting a linear equation to the observed data.
- Multiple linear regression – The regression of a dependent variable on more than one independent variable.

Multiple regression techniques - Techniques by which multiple linear regression models are assessed to determine the independent variables that have the greatest influence on the dependent variable.

Determination, Coefficient of – Also referred to as R-squared value. The square of the product moment correlation between two variables, so called because it expresses the proportion of the variance of one variable, Y, given by the other, X, when Y is expressed as a linear regression on X. More generally, if a dependent variable has multiple correlation R with a set of independent variables, R-squared is known as the coefficient of determination.

Standard Error of Estimates (SEE) – is a measure (estimate) of the accuracy of predictions (the estimated standard deviation of the error in the model). Note that the true value is unknown, by definition, so the standard error of an estimate is itself an estimate.

Unweighted mean – The mean of a set of observations in which no weights are attached to them, except in the trivial sense that each is weighted equally.

Post-hoc Analysis – Refers to statistical analysis after the data has been collected and investigating trends that were not specified before the study was conducted.

Confidence intervals – Gives a range around the estimate of a mean from a sample such that if samples of the same size are taken repeatedly from the same population and a confidence interval is calculated for each sample then 95% of these intervals should contain the true population mean.

6 Abbreviations

ATP	Adenosine Triphosphate
BMI	Body Mass Index
BMR	Basal Metabolic Rate
COMA	Committee on Medical Aspects of Food and Nutrition Policy
CV	Coefficient of Variation
DLW	Doubly Labelled Water
DRI	Dietary Reference Intake
DRV	Dietary Reference Value
EAR	Estimated Average Requirement
EE	Energy Expenditure
EFS	Expenditure Food Survey
EI	Energy Intake
EPOC	Excess Post Exercise Oxygen Consumption
FAO/WHO/UNU	Food and Agriculture Organisation/World Health Organisation/United Nations University
FFM	Fat Free Mass
FFQ	Food Frequency Questionnaire
FM	Fat Mass
GDA	Guidance Daily Amount
GE	Gross Energy
HR	Heart Rate
HRM	Heart Rate Monitor
HSE	Health Survey for England
J	Joule
KJ	Kilojoule
ME	Metabolizable Energy
MET	Metabolic Energy Equivalent
MJ	Megajoule
NDNS	National Diet and Nutrition Survey
NFS	National Food Survey
NME	Net Metabolizable Energy
NEAT	Non-Exercise Activity Thermogenesis
PA	Physical Activity
PAEE	Physical Activity Energy Expenditure
PAL	Physical Activity Level
PAR	Physical Activity Ratio
REE	Resting Energy Expenditure
RMR	Resting Metabolic Rate
RQ	Respiration Quotient
SACN	Scientific Advisory Committee on Nutrition
SEE	Standard Error of Estimate
SI	System of Units
SPA	Spontaneous Physical Activity
TEE	Total Energy Expenditure
TEF	Thermic Effect of Food

7 Membership of Energy Requirements Working Group

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Appendix 1. Doubly labelled water technique

208. The doubly labelled water (DLW) technique is a minimally invasive stable isotopic method of measuring CO2 production in free living subjects over a period of several weeks. The subject drinks a weighed amount of the DLW containing known amounts of the stable isotopes of hydrogen (2H) and oxygen (18O2), based on their body weight. The isotopically labelled water equilibrates with normal body water and a sample is taken typically after about 5 hours to measure the initial isotope enrichment which also indicates from isotope dilution the size of the total body water pool. As water is lost from the body in urine, sweat and evaporation from the lungs during normal water turnover, the labelled water containing 2H and 18O2 is lost. However 18O2 in water exchanges with the oxygen in CO2 because of the carbonic anhydrase reaction. This means that CO2 excretion will also result in an additional loss of 18O2 as C18O2. This means that 18O2 leaves the body faster than 2H, the difference being proportional to CO2 production. Loss of the two isotopes from body water is assessed by measurement of the rate of decline in concentration of the isotope in a sample of the subject's urine or saliva, collected during the study period, and measured by isotope ratio mass spectrometry. The difference between the elimination rates of the two isotopes reflects the rate at which CO2 is produced from metabolism. Energy expenditure can then be estimated from the CO2 production rate after assigning an energy value to CO2 calculated from the assumed average respiratory quotient (RQ) value (ratio of CO2 produced to the O2 consumed), which is determined by the balance of macronutrients oxidised during the period. This in turn is assumed to reflect the composition of the dietary intake.

209. The accuracy and precision of the DLW method for measuring energy expenditure is influenced by isotope fractionation during evaporative water loss and CO_2 excretion. Corrections for isotopic fractionation of water lost in breath and (non-sweat) transcutaneous loss need to be made when using labelled water to measure water turnover or CO_2 production [133]. The technique, therefore, is based on assumptions about the amount of water lost from the body by evaporation and the extent of incorporation of ^{2}H and $^{18}O_2$ into body tissues, especially during growth. This technique, however, provides an indirect measure of TEE and is the most accurate available measure in free-living subjects. The TEE is the energy expended during a time period and, therefore, does not include the energy content of tissue laid down (growth, pregnancy, weight gain) or milk produced during lactation; these are estimated from analysis of tissue deposition and milk secretion. The TEE does include the energy required for tissue synthesis during a time period.

Methodology critique

210. Although the DLW method has become established as the method of choice for the estimation of free living TEE, uncertainties exist about its application and, consequently, in the interpretation of published DLW studies. As this report relies almost entirely on information on energy expenditure determined by the DLW method some of the important issues in relation to the reliability of DLW studies are briefly discussed.

211. The application of the technique has not been standardised, with different approaches taken in both laboratory isotopic analysis and in the experimental design of the measurement of $^{18}O_2$ and $^{2}H_2$ turnover in body water. The three most widely used approaches are the

'slope-intercept', '2-point' and 'modified' methods of calculation. This lack of standardization means its potential high precision (the within-individual CV for the validation of energy expenditure from DLW against respiratory gas exchange) is not always realised. A double-blind between-laboratory variability study identified substantial between-laboratory variability in results, in some cases with precision as low as 35% and with some reporting physiologically impossible results[134]. This seems to reflect analytical error rather than methods of calculation or the approach used to assess isotope decay rates. The different approaches are in principle equally valid although some reviewers suggest that collecting samples repeatedly over the measurement period rather than by collecting them only before and after the measurement period may decrease the error to a small degree. Of the data sets assembled for this report the adult values from the Beltsville study[62] involved the multipoint slope-intercept approach while the OPEN study[135] involved the 2-point approach. However the data set assembled for children and adolescents involve reports from many different laboratories so that between investigator errors could represent cause for concern in our identification of energy reference values for this population group.

212. Estimates of measurement precision vary between investigators. Not all document error terms for the dose, background determinations or uncertainties in fractionated evaporative water loss and RQ. A change in background $^{18}O_2$ enrichment in water during the study because of travel or a change in the dietary water source could affect the final CO_2 production rate, especially in subjects where very low isotopic dosing is used. Observed variation in repeated measurement studies will reflect both methodological error as well as actual variation in TEE due to a change in behaviour, making interpretation difficult. In one study, careful duplicate measurement of TEE in six adult women at a 6 month interval indicated that the within-subject coefficient of variation (CV) for TEE was 7.8%, most of which was estimated by the investigators to be physiological variation (6.4%) due to variation in activity[136]. They also reviewed 16 studies with at least two DLW measurements, which indicated the reliability of the method to be 7.8%, except under conditions of high water flux.

213. Within the OPEN study, repeated isotopic analysis and repeated DLW measurement in a subset of 25 subjects identified an overall CV of the TEE measurement of 5.1%, of which 2.9% was due to analytical and 4.2% due to within individual physiological variation[135]. Others have identified a value for analytical variation of 4%[137]. Within the Beltsville study repeat DLW measurements were conducted in a subset of 32 subjects and identified an overall CV of 12.6%. As the repeat measures were more than 1 year after the initial measurements, unlike the OPEN subset study which compared repeat measures after 2 weeks, it might be expected that variation would be larger. Some of the individuals in the Beltsville subset study[62] exhibited TEE in the second study of only 50% of the first. This highlights the difficulty of identifying rates of TEE within free living populations of relatively small sample sizes.

214. The application of the DLW approach usually involves 7-14 day measurements; however how representative this is of energy expenditure in the longer term is unknown. The Beltsville subset study points to potential errors in this assumption, e.g. the r^2 of the second measure compared with the first was only 0.35. Individuals are likely to change their physical activity with time because of differences in seasons and other reasons resulting in potentially considerable within person variability. Concerns have been expressed about this issue[138] and about the design of the OPEN Study due to the within-person CV of TEE (5.1%) which appears too low when compared with values obtained from a quantitative review of

the reproducibility of TEE measured by DLW in 25 studies with repeated measurements[139]. In this latter review, estimates of 8% for within-subject variation in DLW measurements were reported. This estimate included analytical errors plus inherent within-subject biological variation in energy expenditure due to changes in weight, season and physical activity. This biological variation increased as might be expected with increased time between measurements to about 15% at a time span of 12 months. The authors of the OPEN study[140] subsequently reanalysed the data from studies examined in the review and found that for studies of only free-living subjects (as in the OPEN study) within person variation did not increase with time. The Beltsville study, however, shows a large increase in the CV when replicate studies are conducted over a longer time period.

215. Another potential concern is the influence of growth on measurements due to sequestration of isotope within body tissues during the study. Deuterium can be incorporated into tissues during reductive biosynthesis especially of fat and cholesterol. Such sequestration would decrease the difference in $^{2}H_2$ and $^{18}O_2$ decay rates and lead to an under-estimation of CO_2 production and energy expenditure. The extent to which this is a problem is a difficult question to resolve. Technical problems in assessing the relative influences of isotope sequestration and isotope fractionated water loss, which have opposite influences on estimation of TEE, make the effect on TEE measures in rapidly growing infants difficult to assess. A consensus review[141] concluded that under extreme anabolic conditions and using pessimistic assumptions regarding *de novo* fat synthesis, the maximum error in estimation of TEE due to ^{2}H sequestration could be 5% but that 'it seems unlikely that the error would be as high as this under many circumstances'.

216. The extent to which increasing body fat can influence the method is also an issue. One study in obese and lean subjects identified an underestimation of TEE by DLW of 0.285 MJ/day for each additional 10 kg of fat[142]. Others, however, have failed to observe such an effect [143].

217. Another potential problem is recruitment bias. Subject selection in any study requires subjects to either volunteer or to agree to participate when randomly approached and this raises the possibility of the healthy volunteer effect with study subjects atypical of the general population, in this case more physically active with higher than average rates of TEE. In a validation study for NDNS, DLW studies were conducted in a small adult population (n=66) indicating mean PAL values of 1.73 (range 1.36- 2.2) for women and 1.88 (range 1.37- 2.50) men. These values are on average higher than those of the two large population studies used in this report to identify adult population PAL values possibly because they exhibited the healthy volunteer effect (although it could simply reflect the smaller cohort size). For the OPEN study, volunteers were derived from a random sample of 5000 households so the healthy volunteer effect is likely to be less than in the Beltsville study with subjects recruited through advertisements and letters of invitation. The fact that the distribution of TEE was so similar in these two studies would tend to suggest that recruitment bias was not a significant factor.

Summary

218. It is likely that recent DLW studies have benefited from the experience gained with the method over 25 years of its use. The data set of DLW studies used to derive the EAR for children and adolescents in this report, however, includes a wide range of studies assembled over many years and by many investigators. Although technical problems can be minimal

with careful investigators, some caution must be used in examining this data set.

219. More importantly, however, is the difficulty posed by true, within-individual variation in physical activity and consequent TEE. To illustrate this the repeat DLW assessments of TEE conducted more than 1 year after the first measurement in the Beltsville study are given below (see Table 18)[62]. The within-subject average CV for TEE of 12.6% was just over half the between-subject average value of 22.8% for the larger whole cohort. Some of this latter figure reflects between-subject variation in TEE with size through BMR. After adjusting for BMR and calculating PAL there is a lower CV of 15.4%. During the within-subject repeat measurements of TEE, the subjects were generally weight stable and the BMR would not be expected to have changed. This means that most of the variance must reflect change in physical activity. The within-subjects CV and the CV of the between-subject PAL values are similar: 12.6 % compared with 15.4%. This indicates the difficulty of identifying energy requirements with any certainty for individuals and small groups of subjects, which are likely to reflect average values for extended periods of time.

Table 18. Beltsville DLW data set: within and between subject variability

	within subject CV* %		between subject CV** %			
	TEE	n	TEE	n	PAL	n
Normal	12.1	19	20.2	210	16.2	203
Overweight	12.4	14	22.4	186	14.4	179
Obese	15.5	9	20.8	101	15.4	96
All subjects	12.6	42	22.8	497	15.4	478

* as reported by Moshfegh *et al* (2008)[62]
**Calculated directly from the data set

Appendix 2. The physical activity level (PAL) and its use in the prediction of energy requirements

Theoretical aspects of calculation of PAL and its factorial prediction

PAL as an index of TEE adjusted for BMR

220. The daily rate of total energy expenditure, (TEE), for individuals or groups can be expressed as a multiple of basal metabolic rate (BMR), which has been defined as the physical activity level (PAL). This allows prediction of TEE and consequent energy reference values as PALxBMR each of which represents a physiologically generalizable and predictable term. The introduction of the concept by FAO/WHO/UNU in 198533 was considered a simplifying approach to the determination of energy reference values. Thus BMR, a relatively fixed function of body composition, which is predictable as a function of weight, age and gender, is separated from all other components of energy expenditure which are assumed to be variable. These other components reflect dietary intake, through the heat increment of feeding, miscellaneous thermogenic influences, and lifestyle in terms of physical activity. Thus in principle PAL is an index of TEE adjusted for BMR, which should mean it is independent of weight, age and gender. While most have embraced the concept, important reservations have been expressed[59;144] with preference given to an alternative approach based on multiple regression techniques to develop prediction models of TEE as a function of measured predictor variables such as body weight or age. These reservations need to be addressed.

221. Firstly it has been implied[59] that this factorial approach is not sufficiently evidence based. This presumably refers to the approach as introduced by FAO/WHO/UNU 1985[33] when in the absence of an extensive database of measures of TEE, not only BMR but also PAL was predicted from time allocated calculations of PAR values (activity cost/BMR). As discussed below there are limitations with PAL values determined in this way but direct assessment of PAL from measured TEE and BMR is evidence based.

222. Secondly it is argued that body weight predicts more of the variance in TEE than RMR and consequently "the regression based approach provides a more physiologically appropriate model for TEE, as compared to the PAL approach which assumes TEE is composed of multiples of RMR[59]". Body weight could explain more of the variance in TEE than BMR if a) within the population group under examination variability of physical activity is relatively small and b) any influence of weight on physical activity is very marked, but within the data sets examined here there is little evidence that these conditions apply. For the adult data set (Appendix 10), the regression of TEE on weight, height, age and gender has the same r^2 value (0.62) as that for TEE on BMR (0.63) with BMR capturing all the variance in TEE associated with weight, height, age and gender in a factorial regression model. Analysis of the large DLW data sets for children and adults published in the US DRI report[20] shows that for adults weight was not a significant predictor in a multiple regression with weight and RMR (r^2 values: RMR = 0.56: weight= 0.34). With children[144] where the variance in PAEE is less marked than in adults, according to the DRI data sets of individual values for children, RMR explained slightly more of the variance in TEE than weight (r^2 = 0.88 for RMR and 0.82 for weight). Thus PAEE is an important determinant of the variance in TEE in children and adults with only a minor relationship with bodyweight. On this basis regression models

of TEE with body weight are arguably physiologically limited since they fail to account for the main between individual source of variation in energy expenditure, PAEE.

223. Thirdly a theoretical argument against the BMR multiple approach has been presented[59] that "the PAL model assumes a linear relationship between TEE and RMR that has a slope equivalent to PAL and a zero intercept" and that "The presence of significant and variable intercepts in the regression equations relating total energy expenditure to either RMR or weight invalidates the use of the traditionally used ratios (i.e., TEE/RMR or TEE/body mass) for expressing total energy expenditure data".

224. In fact the PAL model as used in this report makes no assumptions about the regression relationships between TEE and BMR and such relationships are not strictly relevant to the discussion of the use of PAL within the factorial model of describing TEE. This is because it has never been suggested that PAL should be calculated as the slope of a linear regression of TEE on BMR for a population group. With information on TEE and BMR, individual subject PAL values can be calculated. In this way the distribution of PAL values for the population group can be calculated and the way in which PAL varies with age, body weight and any other demographic variable can be usefully examined. This has been the approach adopted for this report.

225. Much of the criticisms and confusion over the BMR multiple approach derives from attempting to fit linear regressions to DLW data derived from studies of children. In this case there does appear to be somewhat less variance in physical activity at any particular age or weight and in addition there is on average, an increase in physical activity and consequent PAL values with these variables. This means that the relationship between TEE and BMR is not linear. With small data sets analysed by linear regression the between individual variation in PAEE will give varying slopes and intercepts which will be inversely correlated and it is therefore not surprising that this has been observed by Carpenter *et al* (1995)[144]. In the 2004 FAO/WHO/UNU report[13] while a simple linear regression of TEE on weight was satisfactorily applied to infants in the first year of life, for children aged 1-18 years a quadratic polynomial regression equation of TEE on weight was derived from the DLW TEE data. PAL values were then extracted from this analysis by comparing TEE with BMR for each age group. These PAL values increased with age and the variance in PAEE at any age was expressed by calculating PAL values ±15% for children after the age of 5 years. This change with age in PAL is apparent in the data set of mean TEE, BMR and PAL values assembled in this report for children (see Appendix 9). There is an obvious and marked increase in PAL after the age of three and then to a lesser extent in older children (Figure 11 Appendix 9): i.e. the plot of TEE on RMR is clearly curvilinear as PAL increases with age. Only when weight becomes a minor predictor of PAEE but explains most of the variance in BMR will the slope of TEE on BMR tend towards the mean PAL and the intercept tend towards zero. This is observed within the combined Beltsville-OPEN adult data set[61;62] assembled for this report. As shown in Figure 16 (Appendix 10), the intercept of the line of best fit of TEE on BMR is not significantly different from zero and the slope is similar to the median PAL.

226. The question of variation of PAL with body weight i.e. the influence of body weight on the energy cost of specific activities is nevertheless an important issue which needs to be examined separately. When the use of PAL was introduced by FAO/WHO/UNU in 1985[33] PAL values were estimated with factorial calculations of time allocated energy costs of individual activities, expressed as PAR values. These were used to identify categories of

activities based on lifestyles, so that those engaged in identifying energy requirements could make such calculations for specific population groups. To this end lists of PAR values for activities are reproduced in the recent FAO/WHO/UNU report[13] (on the basis of a comprehensive review[34]), and MET values for various activities are listed in the US DRI report[20]. Thus, each of these reports assumes that having derived a PAL value for a particular lifestyle, it can apply equally to individuals regardless of body weight. However, careful calorimetric studies have shown this to be not strictly the case: i.e. PAR values increased with weight[145]. The directly measured energy costs of a fixed programme of work expressed as a BMR multiple increased with body weight between 48 and 80kg by about 13% of the mean cost of the activity. This was consistent with theoretical calculations reported by the authors. The implications of this are that the energy requirements of adults engaged in similar tasks will be higher in large compared with smaller adults. The authors showed that for a 40kg adult, the energy requirement calculated as PAL x BMR with PAL derived from measurements of PAR values for the specific activities in a 70kg adult will be an overestimation of about 10%.

227. However this effect of body weight on PAR values for specific activities is only of practical importance on the assumption that PAL can be calculated from a factorial, time-allocated list of the PAR values with any confidence. As discussed below, such predictions of PAL values are unlikely to be accurate and are not recommended in this report.

228. The final issue of general importance for this report is whether there is an influence of gender on PAL. Gender differences in PAL and hence the predicted energy requirement was a feature of the 1985 FAO/WHO/UNU[33] energy report and the 1991 COMA DRV report[1]. Gender differences in behaviour are said to influence overall TEE, and hence PAL values, for similar lifestyles or activities[146]. However most studies have failed to identify differences between men and women in PAEE or PAL, and both recent reports argue that average energy costs of activities expressed as a multiple of BMR, or PAR, should be similar for men and women[13;20].Within one meta-analysis of DLW derived TEE values, PAL values were observed to be 11% lower in women than men, but it was not possible to identify whether this reflected an absence of subjects recruited from more active groups or a general tendency of women to be less involved in strenuous activity[14]. In the DLW data sets examined in this report no differences in PAL with gender were identified for children or adults.

229. In summary therefore none of the concerns expressed above regarding the use of the BMR-multiple approach are likely to be of importance within the framework of this report. As developed below, estimates of PAL values for population groups are best derived from individual measurements of TEE and BMR and not by regression approaches. Within the adult data set assembled here there is no evidence of any significant variation of PAL with either weight or gender (Appendix 10). For children, individual PAL values do show some increase with age and weight but these are almost certainly behavioural changes with development which in no way detract from the validity of the use of the BMR-multiple approach.

Factorial estimation of PAL

230. When the concept of PAL was introduced by FAO/WHO/UNU in 1985[33] it was implicit that PAL values could and would be estimated from the time allocated summation of individual activity energy costs expressed as PAR values. This formed the basis of the 1991 COMA report on DRVs[1], and the principle is embodied within both recent reports[13;20]. This

approach is not adopted here for the following reasons.

231. Firstly, there is disagreement about how to use published PAR values for the calculation of PAL. FAO/WHO/UNU[13] used PAR values from a list compiled specifically for the report[37]. The authors of the US DRI report[20] express concern that factorial calculations from published PAR values may underestimate daily TEE because of lack of specific inclusion of energy expenditure associated with feeding (TEF) or EPOC. In that report[20] PAR values were derived from a list of MET values for specific activities (1MET = a fixed rate of oxygen consumption/kg). The MET values were converted to the BMR multiple PAR values (a ≈7% reduction) and then increased by 26.5% to account for TEF (10%) and EPOC (15%: i.e. increase by 1.15*1.10, see legend to Table 21). Thus the factorial calculations in this report were made from values which were about 26.5% greater than those in the FAO/WHO/UNU report[13]. Because there is no evidence that this is justifiable in all cases, some PAR values may be overestimated by up to 26.5%.

232. Secondly, even if PAR or ΔPAL values are known with certainty, variation in spontaneous physical activity (SPA[24], see paragraphs 23-26), both within and between specific designated activities can introduce considerable error in factorial predictions of PAL. The concept of SPA or non exercise activity thermogenesis (NEAT[147]) is that energy expenditure is variable between individuals because of the variable expression of a behavioural phenotype associated with high levels of physical activity: i.e. SPA is an "inherent propensity to locomotion[24]". This concept derived from observations of greater than expected variation in energy expenditure during calorimeter studies where "workout" type activity is restricted. In these circumstances activity is limited to daily living and postural changes yet PAL values ranged from 1.2-1.7[22-24] (see below). In free living circumstances the potential for such behaviour is more marked[147] and calorimeter- measured PAL values predict the range of higher free-living PAL values[24]. It is highly unlikely that subjects with a high SPA phenotype would ever exhibit the range of PAL values associated with the sedentary category of 1.40-1.69 identified by FAO/WHO/UNU[13] even if they had the seated occupations assumed for this category.

233. Thirdly, some individuals may have what is to some extent the opposite of the SPA phenotype, exhibiting marked compensatory *reduced* activity after periods of intense activity. Such a phenotype has not been widely investigated but has been reported in at least one study in which quite variable PAL values were observed in subjects engaged in highly controlled work activities[145]. PAL varied markedly between 1.53 and 2.08 mainly because of marked differences in discretionary activities. Thus subjects with the lowest DLW-determined PAL values (1.58 n=5) reverted to the basal state between-work periods exhibiting mean PAR values for discretionary energy expenditure of 1.02. The rest of the group exhibited discretionary PAR values averaging 1.89 (n=8) with higher average PAL values (1.95).

234. The existence of such behavioural phenotypes is increasingly being recognised within the context of energy balance regulation[23;25] although their frequency within populations is currently unknown. Nevertheless for such phenotypes, energy expenditure is unpredictable within factorial models which have been deployed to date. In other words, there may be a continuous spectrum of behavioural activities ranging from fidgeting while being otherwise stationary and choosing to walk up escalators briskly rather than stand still on them to adopting a resting posture whenever the possibility presents. Some indication of the extent of

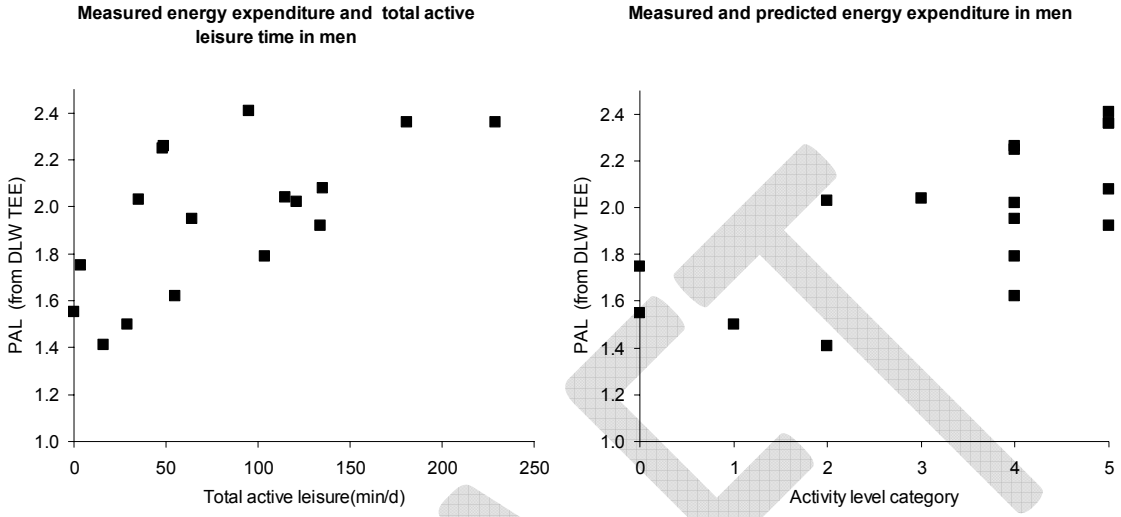
this is can be identified from studies showing individual PAL values within specific activity categories reviewed below.

Observed variation in PAL within specific population groups

235. Many published studies of PAL values of population subgroups only include mean values, but where individual values are reported a much greater range of PAL values is often observed than would be anticipated. As already indicated 24-h restricted activity studies within a calorimeter have repeatedly shown wide variation in PAL values: from 1.15-1.7 in one report of 177 subjects[22] and from 1.20-1.65 in a second report[24], in the latter case with individual values correlating with free living DLW-measured PAL (1.35-2.15). PAL values of urban Chinese adults with manual or sedentary occupations classified into activity categories varied within these categories by up to 0.7[148]. Within a group of inactive men and women studied prior to a training programme the range of PAL values was 1.5-2.2[149]. In a study of older people investigating energy expenditure, self reported physical activity and mortality, there was no relationship between self reported activity and PAL even though PAL predicted mortality[117].

236. The difficulty of predicting PAL values in terms of reported or measured physical activity is exemplified by a study of men with sedentary occupations but varying levels of physical activity[150]. Figure 5 shows a comparison of PAL with either measured activity time or activity categories predicted by the authors from the activity diaries. The relationship between measured PAL and recorded physical activity is only moderate. Thus total active leisure time and activity level category explain only 41 and 48% of the variation in PAL. Subjects with a PAL $\geq$2 recorded leisure activities ranging from 35 to 229 minutes per day and were categorised into categories 2-5. Within three of the 5 categories individual PAL values varied by 0.6 and the difference in PAL between the lowest subjects in category 5 and the highest in category 1 was only 0.17 PAL units. The authors of this study emphasise the large differences which can occur between highly active individuals with a large exercise capacity compared with untrained individuals in the potential energy expended in tasks which are only loosely defined within activity diaries. This explains some of the poor correlation shown in Figure 5. Whatever the explanation for the discrepancy, it is clear that if the energy requirements of these subjects were individually predicted from their activity categories, there would be substantial errors.

Figure 5. Relationship between PAL and measured leisure time activity and categorised activity level[349]



237. Within a data set of DLW studies in healthy adults assembled for this report, all of the studies which report PAL values (n=63) were examined for descriptions of the activities/lifestyles of the subjects. Just over half the studies (n=33) provide no information, but for those that do (n=30), the mean PAL values were assigned to categories of light, moderate or heavy, with those studies with a mixture of activities assigned to moderate. The values in Table 19 show that, notwithstanding the somewhat arbitrary assignment to activity categories, the range of mean study PAL values is considerable, especially in the "light" category (1.23-1.98).

Table 19. Mean PAL values from DLW studies assigned (where possible) to activity groups

Number of studies	Activity category*	PAL value	
		mean	range
33	none	1.73	1.42-1.97
15	light	1.67	1.23-1.98
12	moderate	1.84	1.63-2.01
3	heavy	2.09	1.91-2.48
63	all	1.75	1.23-2.48

* activity categories assigned on the basis of written comments by study authors

238. Although we have not conducted an exhaustive review, it is clear that considerable variation in overall rates of TEE and PAL occur within subjects who would be classified as exhibiting similar lifestyles. As the values shown in Table 19 are mean study values, the range of individual values will, in fact, be much wider but because so few studies report individual PAL values within occupational or lifestyle categories, the extent of inter-individual variability of PAL is hard to judge. Thus with the exception of groups at the extreme of the range (either very restricted or with high levels of physical activity) the

relationship between PAL and lifestyle, or even self-reported physical activity, appears to be weak. Because of this, predictions of PAL values are unlikely to be accurate and are not recommended in this report.

Magnitude and variation in PAL within the general population

Observed lower and upper limits of PAL

239. The FAO/WHO/UNU 1985 report identified the lower limit of PAL, a 'survival' value, to be 1.27, which is consistent with studies assembled elsewhere in non-ambulatory chair-bound and non-exercising subjects confined to a calorimeter (where PAL values of 1.17-1.27 were observed)[15].

240. The lower limit of energy expenditure in subjects who are ambulatory but only exhibiting the minimal activities associated with daily living (e.g. grooming, showering and dressing), is between 1.35 and 1.4[29-31]. In grossly obese subjects confined to a whole-body calorimeter following a standardised sedentary protocol apart from two 30-min exercise periods (30 min of cycling at 25W and 30 min of stepping on and off a 20-cm block at a rate 40/min) mean PAL values were 1.35 (1.27-1.42)[143]. In free- and independently-living healthy extreme elderly subjects, the mean PAL value (after trimming for PAL values <1.1) was 1.38[32].

241. The US DRI report compiled a list of activities of daily living, which accounts for about 4 hours in total and amounts to a ΔPAL of 0.29[20]. This is reported to equate to a sedentary PAL of 1.39, i.e. 1+0.1(TEF) +0.29. Such calculations, however, can only be relevant for subjects in the basal state for 20 hours per day. In any case the listed activities may overestimate actual costs since they include additions of energy expenditure (≈28%) to allow for corrections in TEF and EPOC.

242. Overall, a PAL value of 1.38 seems the likely lower limit for free living individuals. This suggests that the *upper limit* of the sedentary PAL range (1.4) suggested in the US DRI report is too low.

243. The upper limit to human physical activity is that exhibited for limited periods of time by elite endurance athletes and soldiers on field exercises, for whom PAL values between 3 and 4.7 have been reported[15;27]. The maximum PAL value associated with a sustainable lifestyle within the general population, however, appears to be about 2.5 [14;28]. This value has been supported by subsequent studies in long term exercising women [151] and physically active men [14;28;152;153].

Observed magnitude and variation in PAL

244. Several large data sets of TEE measures have been made available to the Committee which contain individual PAL values. These include the US DRI data set[20], the Beltsville study[62] and the OPEN study[60;61]. Although the OPEN study did not measure BMR, this has been calculated using the Henry BMR prediction equations based on weight and height. The distribution statistics for these three large data sets are shown below in Table 20. Details of the OPEN and Beltsville cohorts are given in Appendix 10.

245. The US DRI data set of adults aged 18 or more years (n=767, 360 overweight or obese and 407 normal weight) includes the data in the Black *et al*. (1996) analysis[14]. There is a fall

in PAL with age, most notably in terms of lower values in the small sample at ages greater than 80 years for both the normal and overweight/obese populations. Gender differences in mean PAL values are only apparent within the overweight/obese group, but the difference is small. The characteristics of this data set shown in Table 21 are those after trimming to exclude the very old (aged >80 years). The median (1.72) is higher than the median values for the OPEN and Beltsville studies. The US DRI data set is, however, a collection of many individual studies with much smaller sample sizes, and cannot be considered as representative of a normal adult population. There may be an over representation of subjects with PAL values >2, i.e. very physically active subjects, as indicated by the 90th centile value of 2.10 compared with 1.96 and 1.92 for the Beltsville and OPEN studies, respectively.

Table 20. Distribution of PAL values of large data sets

Distribution boundaries	US DRI (n=724; age 18-80y)	OPEN (n=451; age 40-69y)	Beltsville (n=478; age 30-69y)
10th centile	1.38	1.40	1.32
lower quartile	1.55	1.49	1.46
median	1.72	1.61	1.62
upper quartile	1.92	1.77	1.78
90th centile	2.10	1.92	1.96

246. In the OPEN study [60] mean PAL values fall slightly with age (from 1.70 at 40 to 1.57 at 70), are slightly higher for women than men (by 0.04 units), but are independent of weight or BMI. The distribution pattern of PAL values is clearly shifted downwards compared with the US DRI data set values.

247. In the Beltsville study[62] there is no change of PAL with age or with BMI (by regression or with category). Thus the possibility that the energy cost of physical activity may be affected by adiposity[154-156] does not seem to influence the range of PAL values within normal and obese subjects. The distribution is similar to the OPEN study for the lower and upper quartiles and median, which, to some extent, lends confidence to the calculation of BMR in the OPEN data. For the Beltsville study, however, the 10th centile is slightly lower (1.32) and the 90th centile is slightly higher (1.96), than in the OPEN study (1.40 and 1.92).

248. The characteristics of PAL values within the combined OPEN-Beltsville cohort are shown in Appendix 10.

Observed effect of additional physical activity on PAL

249. The energy cost of additional amounts of sport or strenuous leisure activity has been considered in terms of ΔPAL values. One widely quoted meta-analysis of DLW studies[14] reported that mean PAL values increase from 1.63 to 1.99 with imposed activity (physical training) on a low activity background.

250. Adults with normally sedentary occupations who did not exercise or play sport on a regular basis increased PAL by 0.41(0.04-0.81: from 1.59: range 1.43-1.68, to 1.99: range 1.66-2.42) with a 9 week incremental programme of jogging up to 1 h/d, 5 d/week)[157]: Inactive men and women following a 40 week incremental running programme sufficient to

enable running a half marathon increased their mean PAL values by 0.44 PAL units above their initial range of 1.5-2.2)[158]: obese boys achieved a mean increase of 0.27 with a 4 week training program of cycling for 45 minutes 5 times/week at 50-60% of VO_2max (i.e. from 1.77 (±0.15) to 2.04 (±0.15)[159]. The implications of these studies in the light of theoretical calculations of the likely response of PAL to exercise are considered at the end of this section.

251. Individuals involved in competitive sport or who have habitual high levels of physical activity exhibit PAL values up to 0.6 units higher than those who do not take regular exercise. In a small number of healthy men, there was a mean difference in PAL of 0.64 between competitive runners (PAL = 2.26) and those reporting no leisure activity[153]. In women aged 50-70 years there was a mean difference in PAL of 0.61 between long-term exercisers (PAL= 2.48:range 1.60–3.43) or long-term non exercisers, (PAL= 1.87: range 1.63–2.25)[151].

Predicting the effect of additional physical activity on PAL

252. The US DRI report lists the energy cost of various activities in terms of METs and ΔPAL values[20]. Selected examples, including those for walking, are given in Table 21, together with actual additional rates of energy expenditure associated with the activities calculated for standard woman (57kg age 30-60 years) and man (70kg age 30-60 years)[57]. As indicated above, such ΔPAL values are calculated from METs after adjustment of the equivalent PAR value to include an additional 26.5% to account for TEF and EPOC. The calculations are similar but not exactly the same (see note b) and could be overestimates if the MET values were not obtained in subjects in the basal state. They will be higher than equivalent values quoted by FAO/WHO/UNU and others[34]. The ΔPAL values are the increases in the daily PAL expected when the 1 hour of the activity (mean PAR-1/24) replaces the BMR. The ΔPAL values shown in Table 21 are slightly lower than those in the US DRI report because the reference BMR values are slightly different and the additions for EPOC and TEF are made a little differently (x 1.15 x 1.10 =+26.5% in the SACN report and x 1.15 x 1/0.9=+27.8% in the US DRI report). The PAR values can be compared with directly measured values in men with light occupations and variable leisure activities while walking at moderate pace (2.54), walking briskly or carrying a load (4.09) and jogging or running (13.1)[152]. By and large the values compare well.

Table 21. Influence of activities on PAL

Activity	METs[a]	PAR[b]	ΔPAL /10 min[c]	kJ(kcal)/10 min [d]		ΔPAL /h [e]	kJ(kcal)/h [d]	
				woman	man		woman	man
Walking (2mph)	2.5	2.9	0.013	71(17)	91(22)	0.08	436(104)	559(134)
Walking (3 mph)	3.3	3.9	0.02	109(26)	140(33)	0.12	654(157)	839(201)
Walking (4mph)	4.5	5.3	0.03	164(39)	210(50)	0.18	981(235)	1258(301)
Tennis (doubles)	5	5.9	0.034	185(44)	238(57)	0.2	1091(261)	1398(335)
Dancing	6	7.1	0.042	229(55)	294(70)	0.25	1363(326)	1748(418)
Roller Skating	6.5	7.7	0.046	251(60)	322(77)	0.28	1527(365)	1957(469)
Swimming	7	8.2	0.05	273(65)	350(84)	0.3	1636(392)	2097(502)
Walking(5 mph)	8	9.4	0.058	316(76)	405(97)	0.35	1908(457)	2447(586)
Jogging (6 mph)	10	12	0.08	436(104)	559(134)	0.46	2508(600)	3216(770)
Rope skipping	12	14.1	0.091	496(119)	636(152)	0.55	2999(718)	3845(920)
Squash	12	14.1	0.091	496(119)	636(152)	0.55	2999(708)	3845(920)

a:1 MET =0.0175 kcal/minute/kg

b: Energy expenditure as a multiple of the BMR, calculated from METs as follows.

1. Conversion to PAR BMR/multiple values: BMR is calculated as mean BMR value for reference women (57kg age 30-60)=0.0159kcal/min/kg), and reference man (70kg age 30-60) =0.0166kcal/min/kg: Henry BMR prediction equations[41]. The resulting PAR value is 7% lower than the MET value.
2. Addition of 26.5%* for EPOC and the thermic effect of feeding. Note that ΔPAL values are slightly lower than those in the DRI report because the reference BMR values are slightly different and because the additions for EPOC and TEF are made slightly differently (x 1.15 x 1.10 =+26.5% here and x 1.15 x 1/0.9=+27.8% DRI report).

Overall these changes mean that the PAR value is 17.7% greater than the MET value.

c: = (PAR-1)/144

d: = (PAR-1)/24

253. It is important to recognise that the overall effect of an additional activity at some fixed rate will have a variable effect on the PAL value according to the magnitude of energy expenditure which it replaces, even if no other changes in energy expenditure occur.

254. In the US DRI report the factorial calculations of PAL values from MET and ΔPAL values for various activities such as those shown in Table 21 (e.g. walking (4mph) ≡ 0.18 ΔPAL) involve an assumption that each activity replaces the BMR. This implies in turn that its effect on PAL will be the same for all individuals. In practice, much of the non-sleeping time energy expenditure is greater than BMR and may even be much higher for those exhibiting a high SPA phenotype. The effect of an additional activity, such as 1 hour/day walking at 4mph, will be to replace activity likely to be at a higher rate than the BMR and will, therefore, result in a lower increase in PAL. Thus individuals with a low rate of background discretionary activity will experience a higher overall increase in PAL for the extra activity, than those with a higher background rate.

255. This is shown in Table 22, where 1 hours walking at 4 and 5 mph or jogging 10-min miles (ΔPAL values of 0.18, 0.35 and 0.46, PAR values of 5.3, 9.4 or 12.0), replace 1 hours activity in subjects exhibiting PAL values of 1.5, 1.6 or 1.7. Such PAL values in subjects sleeping for 8 hours a day imply average discretionary PAR values of 1.75, 1.9 and 2.05. Substitution of an average hour of discretionary activity with 1 hour of the increased physical activity will result in actual new PAL and ΔPAL values which are 10-25% less than the listed ΔPAL value for the activity. For high SPA phenotypes additional planned activity may have

little effect on overall energy expenditure and PAL. Only if the new activity replaced a period of complete inactivity (PAR=1) will the expected increase be observed. If the additional activity resulted in a period of compensatory reduced activity as discussed above, the overall effect would be even less than indicated. These calculations show the difficulty of calculating a planned change in energy expenditure. In practice, however, because the variation in the magnitude of ΔPAL with mean discretionary PAR is small, and given the insecurities involved in such calculations, this uncertainty is not considered in this report (see paragraph 141).

Table 22. Influence of specific additional activities on PAL in subjects with varying initial PAL values

		1 hours additional planned activity		
		4mph walking	5mph walking	10min mile jogging
	PAR[a]	5.3	9.4	12.0
	ΔPAL[b]	0.18	0.35	0.46
Initial PAL	Mean discretionary PAR[c]	new PAL[d] (actual ΔPAL[e])		
1.5	1.75	1.65 (0.148)	1.82 (0.320)	1.93 (0.427)
1.6	1.9	1.74 (0.142)	1.91 (0.313)	2.02 (0.421)
1.7	2.05	1.84 (0.135)	2.01 (0.307)	2.11 (0.415)

a: Values from Table 21
b: = (PAR-1)/24: assuming the activity replaces a period at the BMR
c: assuming 8 hrs at PAR =1(sleeping)
c: calculated as the1hr activity replacing 1 hr at the mean discretionary rate
e: new PAL-initial PAL

256. Overall, these theoretical calculations indicate that PAL can be increased by about 0.2 for one hours brisk walking (with brisk defined as slightly faster than 4mph), about 0.4 by one hours jogging at 6 mph, and up to about 0.6 by an intense aerobic exercise programme associated with training for competitive sport. This allows a re-examination of a widely quoted statement derived from a DLW meta-analysis[14;15] that 30-60 minutes of active sport 4-5 times per week can raise PAL by about 0.3 units. On the basis of the ΔPAL values in Table 21 and if 'active sport' is equivalent to jogging at ΔPAL per hour of about 0.43, then 30 minutes a day for 4 days a week and 60 minutes a day for 5 days a week would raise PAL on average by about 0.12 and 0.31, respectively. Thus a more accurate statement would be that 60 minutes of active sport 5 times per week can raise PAL by about 0.3 units and this is generally consistent with the observed effects discussed in paragraphs 249-251 above.

PAL values in relation to health outcomes

257. The US DRI report discusses a 'Physical Activity Level Consistent with a Normal Body Mass Index' in terms of one hour of moderately intensive physical activity (walking at 4 miles per hour) resulting in an increase of 0.2 PAL units[20]. The FAO/WHO/UNU 2004 report identified a desirable PAL value of 1.75 or more[13].

258. Information on the relationship between PAL and mortality has recently been published in a prospective study of healthy older adults (n=302; aged 70 to 79 years)[117]. TEE was determined using the DLW technique and BMR by indirect calorimetry. Over an average of 6.15 years of follow-up, participants in the upper tertile of PAEE (PAL greater than 1.78) had a reduced risk of all-cause mortality (HR 0.43, 95% CI 0.21-0.88; $P_{trend} = 0.02$) than

those in the lowest tertile (PAL less than 1.57). Thus this objectively measured free-living PAEE was strongly associated with lower risk of all-cause mortality in these healthy older adults. The published Kaplan-Meier Survival Plots indicate that the separation of survival statistics between the tertiles did not occur until after 2 years following the initial measures. This suggests that the increased mortality in the lowest PAL tertile was not due to reverse causality (i.e. subjects exhibiting low PAL values because they were ill and at increased risk of mortality), but this cannot be ruled out. Although the intensity and type of physical activity was not objectively measured, physical activity questionnaires suggested that the proportion of individuals who reported high-intensity exercise and walking for exercise, in terms of both duration and intensity, was similar across tertiles of free-living activity energy expenditure. This implies that simply expending energy through any activity may influence survival in older adults and that specific, high intensity exercise *per se* may not be required to produce health benefits.

Utilizing PAL values to determine reference energy intakes

259. Notwithstanding the uncertainties of predicting PAL for population groups, it remains the case that all previous dietary energy recommendations have recognised the need to include a variable physical activity factor in the derivation of energy requirements for school children and adults. Although criticisms have been levelled at the BMR x PAL approach, no satisfactory alternative has been identified. There are two major considerations in the practical application of this approach: identifying suitable PAL values appropriate for groups and populations; and utilizing this information to derive energy reference values.

260. In the past, starting with the 1985 FAO/WHO/UNU report, a range of PAL values have been determined by factorial calculations which equate to occupation and lifestyle, with the intention of providing guidance to the health-care professional using the reports in making a judgement about the appropriate PAL value for individuals and population groups. The 1991 COMA DRV report [1] required a choice from a 3 x 3 matrix of PAL values (three occupations, three leisure activities), for each gender over a range of 1.4-1.9 for men and 1.4-1.7 for women. In addition, a table of EAR values calculated for nine PAL values from 1.4 to 2.2 is given. The FAO/WHO/UNU report [13] classified the intensity of a population's habitual physical activity into three categories identified by a range of PAL values for each category: sedentary or light activity 1.40-1.69, active or moderately active 1.70-1.99, vigorous 2.00-2.40, with worked examples using the midpoint of these three ranges. The report then listed tables of daily average energy requirements calculated for six PAL values (1.45, 1.60, 1.75, 1.90, 2.05 and 2.20) with further worked examples for individuals or groups with PAL values not included in the list (i.e. PAL =1.8). The implication of both the 1991 COMA DRV and FAO/WHO/UNU[13] reports is that it is possible to utilize the information on PAR values for activities to predict PAL values for specific population groups to within 0.05-0.1 of a PAL value.

261. The US DRI report[20] included physical activity factors in the prediction equations for TEE for men and women based on weight, height, age and the physical activity variable (PA).

262. The PA factor, which scales the weight and height factors, results in the equation containing a form of PALxBMR, since the height and weight factors should capture the BMR data (in fact, calculations with the published DLW data set within the report, show that

the prediction equations calculate the same values for TEE as PAL x predicted BMR). The PA variable is not PAL *per se*, but constants assigned to each of the four PA categories (sedentary, low active, active, or very active). For men these were: 1.0, 1.11, 1.25 or 1.48; and for women: 1.0, 1.12, 1.27, or 1.45. In effect, this results in four parallel prediction equations for each gender, one for each PAL category. The user of the report must choose the appropriate PA factor by locating the individual or population group under consideration within one of four PAL ranges. It is not clear how these PAL ranges have been derived, but factorial calculations of PAL are derived in the report from lists of ΔPAL values for various activities. The examples shown are for PAL values of 1.39 (sedentary), 1.49 (low active), 1.75 and 1.77 (active) and 2.06 (very active). Assuming that the sedentary PA factor of 1.0 is equivalent to a PAL of 1.39, then the other PA factors in the equation are equivalent to PAL values of 1.54, 1.74 and 2.06 (men) and 1.56, 1.77 and 2.02 (women), which generally correspond to the worked examples.

263. Because the user of the US DRI report is required only to locate an individual within a PAL range rather than a precise PAL value, this makes it, to some extent, simpler than FAO/WHO/UNU procedure[13]. Indeed, with a lower limit of PAL for free living individuals of about 1.38 (see above), few subjects in any population would be assigned to the sedentary category leaving the choice to be made between one of the other three categories. This review has emphasised that choice between adjacent PAL categories would be difficult. Miscategorisation between adjacent categories would result in predicted TEE, and hence energy reference values, being 13-18% too high or low for subjects in the middle of each category, or up to 40% for individuals at the top or bottom of ranges.

264. It is clear from the above that the inter-individual variability of PAL is such that it is an unrealistic expectation that PAL values can be predicted for specific lifestyle-dependent population groups with the precision implicit in any of these previous reports. Furthermore little can be said about the health implications of specific PAL values. Nevertheless the definition of TEE and the energy requirement for a population group on the basis of PALxBMR remains a sound principle and an alternative approach to its use is therefore required.

265. The simplest approach is to decide that TEE for population groups can only be defined on the basis of direct measurements of reference populations from which average PAL values and their distribution can be identified. Thus medians and ranges of PAL values can be identified with reasonable confidence for population subgroups defined only in terms of age, BMI and gender, assuming only that reference population groups are appropriate. This allows prediction of TEE for these populations as a function of the BMR. Dietary reference values can then be framed against such distributions. Such framing could involve an average (median) reference intake for the population together with lower (e.g. 25th centile) and higher (e.g. 75th centile) values identified for those representing the less active or more active sections of the population and with additional amounts of energy likely to be needed for lifestyle changes associated with additional activities.

266. Such advice is clearly a major departure from previous approaches for adults although it is in principle similar to the approach adopted by FAO/WHO/UNU in their recommendations for children. However it is an approach which recognises the reality that prediction of individual rates of energy expenditure is inherently problematic.

Appendix 3. BMR prediction equations

267. The factorial calculation of energy reference values as a BMR multiple for any population group identified in relation to age, gender and size, requires appropriate BMR prediction equations. Also, one of the two large DLW data sets used in this report[60] did not measure BMR values so that extraction of PAL values can only be done with the use of predicted BMR values.

268. The FAO/WHO/UNU energy report[13] calculated BMR with Schofield equations[53;54] (see Table 23). It has been shown that Schofield predictive equations may overestimate BMR in many communities and alternative prediction equations, the Henry equations (see Tables 25 and 26), based on either weight or weight and height have been devised [57] (see paragraphs 270-271).

269. The validity of all published predictive equations for resting energy expenditure was tested in US and Dutch overweight and obese adults aged 18–65 years [58]. The accuracy of the Henry equations (% of subjects predicted within ±10% of the RMR measured) was 79%, which was as good as, or better than, all other equations tested, including the Schofield equations (69% accurate). Against a cohort of Dutch overweight and obese subjects, however, all prediction equations performed less well.

270. The two sets of prediction equations were tested against the US DRI DLW database[20] in which BMR values were measured for most subjects (n=767, age 20-96, BMI 18.5-62, Men n=334; women n=433). The calculated statistics included accuracy, the root mean squared prediction error (RMSE), and the mean, minimum and maximum % difference, (bias), between predicted and measured RMR, as well as mean values for BMR and PAL.

271. The differences between the prediction equations were small, but both Henry equations, especially those based on weight and height, performed slightly better. As a result, the Henry equations based on weight and height were chosen to predict BMR in this report.

272. The inclusion of height, as well as weight, in the Henry prediction equations is particularly appropriate as the range of ideal adult weights was generated from BMI and height categories within BMI bands. Calculation of BMR from height and weight resulted in only minor differences in the predicted BMR compared with weight alone. The difference between the weight alone and weight+ height equations as a percentage of the BMR were, for men, mean =0.93, RMS =1.64, minimum -2.7 maximum 5.6, and for women, mean =0.27, RMS =2.53, minimum -6.5 maximum 5.7.

273. The difference between prediction equations (see Table 26) was least for weights calculated from mean heights for each BMI category (i.e. % differences for men: mean 0.66, RMS 1.07, maximum 3.23, minimum -0.38, compared with weights calculated from lower and upper 2.5 centiles of height (mean 0.66, RMS 1.91, maximum 5.62, minimum -2.72). Percent differences for mean heights for women were mean 0.45, RMS 0.92, minimum -1.51, maximum 2.18 compared with weights calculated from lower and upper 2.5 centiles of height (mean -0.1, RMS 3.68, maximum 5.74, minimum -6.51.

Table 23. Prediction equations for BMR: Schofield* [≠ 13]

	Age (y)	BMR: MJ/day		BMR:kcal/day	
	Y	Coefficient weight: kg	const	Coefficient weight: kg	const
Males	<3	0.249	-0.127	59.51	-30.4
	3-10	0.095	2.110	22.706	504.3
	10-18	0.074	2.754	17.686	658.2
	18–30	0.063	2.896	15.057	692.2
	30–60	0.048	3.653	11.472	873.1
	>60	0.049	2.459	11.711	587.7
Females	<3	0.244	-0.130	58.317	-31.1
	3-10	0.085	2.033	20.317	485.9
	10-18	0.056	2.898	13.38	692.6
	18–30	0.062	2.036	14.818	486.6
	30–60	0.034	3.538	8.126	845.6
	>60	0.038	2.755	9.082	658.5

* Coefficients and constants shown for equations of the form BMR =coefficient x weight (kg) + constant
≠ Equations as quoted by FAO/WHO/UNU 2004 which derive from Schofield, 1985 [54]. These differ slightly from those quoted by Henry (2005) [57] which derive from Schofield, *et al.* (1985)[53-55].

Table 24. Prediction equations for BMR: Henry weight and height*[57]

Gender	Age	BMR: MJ/day			BMR:kcal/day		
	(y)	Coefficient weight: kg	Coefficient height(m)	constant	Coefficient weight: kg	Coefficient height(m)	constant
Males	<3	0.118	3.59	-1.55	28.2	859	-371
	3-10	0.0632	1.31	1.28	15.1	313	306
	10-18	0.0651	1.11	1.25	15.6	266	299
	18–30	0.0600	1.31	0.473	14.4	313	113
	30–60	0.0476	2.26	-0.574	11.4	541	-137
	>60	0.0478	2.26	-1.070	11.4	541	-256
Females	<3	0.127	2.94	-1.2	30.4	703	-287
	3-10	0.0666	0.878	1.46	15.9	210	349
	10-18	0.0393	1.04	1.93	9.40	249	462
	18–30	0.0433	2.57	-1.180	10.4	615	-282
	30–60	0.0342	2.1	-0.0486	8.18	502	-11.6
	>60	0.0356	1.76	0.0448	8.52	421	10.7

* Coefficients and constants shown for equations of the form BMR = coefficient x weight (kg) + coefficient x height (m) + constant

Table 25. Prediction equations for BMR: Henry weight* [57]

Gender	Age	BMR: MJ/day		BMR:kcal/day	
	(y)	Coefficient weight: kg	constant	Coefficient weight: kg	constant
Males	<3	0.255	-0.141	61.0	-337
	3-10	0.0937	2.15	23.3	514
	10-18	0.0769	2.43	18.4	581
	18–30	0.0669	2.28	16.0	545
	30–60	0.0592	2.48	14.2	593
	>60	0.0563	2.15	13.5	514
	60–70	0.0543	2.37	13.0	567
	>70	0.0573	2.01	13.7	481
Females	<3	0.246	-0.0965	58.9	-23.1
	3-10	0.0842	2.12	20.1	507
	10-18	0.0465	3.18	11.1	761
	18–30	0.0546	2.33	13.1	558
	30–60	0.0407	2.90	9.7	694
	>60	0.0424	2.38	10.1	569
	60–70	0.0429	2.39	10.2	572
	>70	0.0417	2.41	10	577

*Coefficients and constants shown for equations of the form BMR =coefficient x weight (kg) + constant

Table 26. Comparison of BMR prediction equations against the US DRI data set

	BMR mean kcal/d	sd	PAL Mean	sd	Accuracy %	RMSE mean kcal/d	Bias% Mean	Min	Max
Reported	1524	300	1.71	0.29					
Predicted values									
Henry wt and ht	1514	273	1.71	0.29	73	114	-0.32	-33	35
Henry wt	1509	292	1.72	0.30	70	121	-0.32	-33	35
Schofield/FAO	1531	278	1.69	0.28	69	123	1.33	-36	43

Appendix 4. Factors affecting energy expenditure

Body size and composition

274. Energy expenditure is related to body size. Both height and weight are important determinants of energy expenditure. In general, larger people have more tissue mass than smaller people and therefore have a higher BMR.

275. The metabolically active tissue mass of the body is termed fat-free mass (FFM) and comprises muscle, bone, skin and organs. FFM is the principal determinant of inter-individual variation in BMR and RMR, after adjustment for body size[160-167]. Fat mass (FM) has been observed to account for a small amount of the inter-individual variation in BMR and RMR in most studies[164-172], but not all[173;174].

276. In adults, variation in the composition of FFM, after adjustment for body size, may also account for a small amount of the inter-individual variation in BMR and RMR [162;163;175-177].

277. In infants, children and adolescents, there is an increase in BMR with age, due to growth and increasing body size. Body composition changes during growth. At birth, the newborn is about 11 % FM. Progressive fat deposition in the early months results in a peak in the percentage of FM (about 31%) at 3 to 6 months, which declines to about 27% by 12 months of age[41]. During infancy and childhood, girls grow more slowly than boys and girls have slightly more body fat. During adolescence the gender differences in body composition are accentuated[39]. In boys there is a rapid increase in FFM, coinciding with the rapid growth spurt in height, and a modest increase in FM during early puberty, followed by a decline; in girls, adolescence is characterised by a modest increase in FFM and a continual accumulation of FM. The pubertal increase in FFM ceases after about 18 years of age[39].

278. Body mass and body composition have been shown to impact on PAEE and TEE in children[178;179] and adults[14;144;180-186].

279. In adults, however, and on a population basis and up to a moderate level of fatness (BMI < 30 kg/m^2), the relative proportions of FFM and FM are probably unlikely to influence energy expenditure in ways other than through their impact on body weight[63]. In adults with higher percentages of body fat composition, an effect on the mechanical efficiency of movement can increase the energy expenditure associated with weight-bearing activities[187].

280. Overweight and obese individuals have been shown to have higher absolute TEE than normal weight individuals, because of the effect of a higher BMR associated with increased body size, both FM and FFM[64;65]. This observed increase in energy expenditure is not in direct proportion to body weight since, when expressed per kg, both TEE and PAEE decline with increasing BMI[64].

Gender

281. Gender differences in energy expenditure are largely accounted for by differences in body size and composition. Women have a lower percentage FFM than men, i.e. they have a

higher percentage FM, and so absolute energy expenditure is lower in women. After adjustment for body size and composition, BMR and TEE have been observed, in most studies, to be lower in girls[188-190] and women[191-194;194;195]; however, some studies have observed no differences in energy expenditure between sexes after adjustment for FFM in children [178] and adults [196;197].

282. In pre-menopausal women, a small increase in BMR, RMR, sleeping metabolic rate and TEE during the luteal phase of the menstrual cycle, has been observed in several studies[191;198-208], although not all[209-212]. This suggests an effect on energy expenditure by sex hormones; in premenopausal women, pharmacological suppression of oestrogen and progesterone release has been observed to reduce RMR[199]. There have been no longitudinal studies of energy expenditure in women across the menopausal transition to determine whether the natural withdrawal of sex hormones influences energy expenditure. It has been speculated that suppression of ovulation with contraceptives could prevent the increase in energy expenditure observed in the luteal phase[207], but results from studies investigating the effect of contraceptive drug use on energy expenditure have been equivocal[206;210;212;213].

Age

283. There is a decline in BMR with older age and this is mainly attributable to the progressive loss of FFM observed with aging [214]; however, a small decline in BMR with age, independent of any age-related changes in FFM, has been observed in most cross-sectional studies [165;197;215-222], but not all [223;224]. The age-related decline in BMR was fully accounted for by a reduction in FFM and proportional changes in its metabolically active components in one study in healthy subjects [216].

284. It is unclear whether changes in the BMR with age are entirely a result of changes in body composition or whether this is related to other factors, e.g. a decline in sodium-potassium ATPase activity, decreased muscle protein turnover, and changes in mitochondrial membrane protein permeability[225]. A difficulty encountered in studies of the effects of aging on the decline in BMR is the differentiation of the aging process itself from common age-associated diseases and the subsequent effects on organ metabolic rates, e.g. left ventricular hypertrophy[216].

285. Physical activity energy expenditure has been observed to decline with aging [225;226], but the results from studies investigating an effect of aging on diet-induced thermogenesis have been inconsistent[227;228].

Genetics

286. Genetic inheritance potentially influences all factors affecting inter-individual variation in energy expenditure, for example body size and composition, and a familial influence on RMR, independent of FFM, age, and sex, has been reported[173;229]. Genotype association studies have largely been restricted to candidate genes whose dysfunction might reasonably be expected to have an effect on energy expenditure.

287. Overall, the results do not show a consistent effect on energy expenditure of any of the different genotypes studied thus far: the adrenoceptors (*ADRB1* [230;231]; *ADRB2* [232]; *ADRB3* [233;233-239]) the leptin receptor gene [240-242], the mitochondrial uncoupling protein genes (*UCP1* [243-245]; *UCP2* [210;245-250]; *UCP3* [210;245] sodium-potassium ATPase genes (*ATP1A1*, *ATP1BL1*)

[251] or the intestinal fatty acid binding protein 2 gene[252;253]).

288. Several other individual studies have found associations between energy expenditure and genotypes for the glucocorticoid receptor gene[254], interleukin-6 gene[255], melanocortin-4 receptor gene[256;257] and the dopamine D2 receptor gene[258]. Genome wide association studies, in several populations, have detected significant linkage on several chromosomes with measures of energy expenditure[259-261].

289. There have, as yet, been no clearly established relationships between specific genotypes and energy expenditure.

Ethnicity

290. Differences in body composition and FFM composition exist between different ethnic groups, for example between white and black[262] and white and Asian[263;264].

291. Most studies, although not all [196;265-268], suggest that BMR, adjusted for differences in FFM and FM, is lower in black subjects than white subjects [194;196;210;269-285]. This difference, however, may be due to racial differences in the composition of FFM, i.e. metabolically active organ mass, rather than ethnic differences in metabolism [160;262;286-288].

292. Racial differences in BMR, adjusted for body weight, between Asian and white appear to be accounted for by differences in FFM and FM [263;264]. Differences in body composition, therefore, appear to be mainly responsible for the reported differences in energy expenditure between ethnic groups.

Endocrine state

293. As discussed above (paragraph 282) sex hormones may affect energy expenditure. Other hormones have also been implicated in the regulation of energy expenditure.

294. Thyroid status is a major determinant of metabolic rate. Hyperthyroidism increases while hypothyroidism decreases RMR [289]. It is unclear, however, whether variation within the normal physiological range of plasma thyroid hormone, tri-iodothyronine (T_3), concentration is associated with variation in BMR, independently of FFM [165;171;290-299].

295. Plasma noradrenaline concentration has been observed to be associated with RMR, adjusted for FFM [293;298], but not all studies have found this association [295].

296. The hormone leptin is involved in energy balance and is produced primarily in white adipose tissue; it is subject to acute regulation, particularly by the sympathetic nervous system [300]. It is unclear whether variation in plasma leptin concentration is associated with variation in RMR, adjusted for FFM and FM [165;240;266;301-312]. Some of the discrepancies observed may reflect problems in accounting for the confounding effects of FM on plasma leptin concentration [306]. Administration of leptin has not been shown to affect RMR [313-317], but during weight loss (negative energy imbalance) leptin may reduce the increased work efficiency of skeletal muscle, seen in response to energy restriction, and thereby reduce the observed decline in PAEE [318;319]. The influence of leptin on energy expenditure is, therefore, unclear.

297. Metabolic stress and fever have also been observed to increase BMR; this is discussed in Appendix 6.

Pharmacological agents

298. Smoking has been shown to increase energy expenditure to a small extent; sympathoadrenal activation by nicotine is thought to be primarily responsible for this effect [66;210;320]. Caffeine has also been shown to increase energy expenditure to a small extent [321;322] and to have an additive thermogenic effect to nicotine [66;321;323;324]. Administration of alcohol was not observed to have an acute effect on energy expenditure in one study [325], but chronic alcoholics have been observed to have a higher RMR, adjusted for FFM, than healthy social drinking controls [326] and abstinence from alcohol reduced the alcoholics' RMR [327;328].

299. Administration of glucocorticoids [329;330], adrenaline [331;332], amphetamines and some anti-obesity drugs [333] have all been shown to increase energy expenditure; whereas, the administration of opiates [334] and barbiturates [335] reduce energy expenditure . Growth hormone administration may increase energy expenditure [336], but this may be partly explained by increased FFM [337]. β-blockers (β-adrenergic antagonists) have also been shown to reduce RMR [338].

Environment

300. Decreases in body temperature, in response to cold exposure, are delayed by reducing heat loss via peripheral vasoconstriction and by increasing energy expenditure by shivering thermogenesis and increasing muscular activity [339], but as ambient temperature remains relatively constant for most people in the UK, shivering thermogenesis is unlikely to be a significant contributor to energy expenditure.

301. A number of studies conducted in the UK and Holland asked adult subjects to execute the same daily activities protocol at different ambient temperatures. The findings suggest that short-term variation (1-3 days) in ambient temperatures of between 16-28°C is inversely associated with sedentary TEE [340;340-347]. Any effect of ambient temperature on BMR, however, is less clear [340-348].

302. Several studies have also reported seasonal variation in measures of energy expenditure, adjusted for FFM, suggesting an increase in energy expenditure during colder months [150;349-351]. Seasonal differences in physical activity levels may also be a factor [152].

303. Overall, these studies suggest that the variation in energy expenditure due to differences in environmental temperature can account for about 2-5 per cent of TEE. The maintenance of indoor temperatures to within 20-25°C and the use of clothes to control body heat loss, however, mean that changes in ambient temperature are unlikely to impact much on energy requirements in the UK.

Appendix 5. Physical Activity and weight

Background

304. The amount of energy expended during physical activity could affect an individual's ability to maintain energy balance. As PAEE is the most variable component of TEE, and is amenable to modification, changes in PAEE may affect risk of weight gain. The rising prevalence of obesity has been attributed in part to population-level changes in PAEE [352;353].

305. The aim of this Appendix is to consider the energy expended during physical activity in relation to risk of weight gain and obesity, and to determine whether a specific level of physical activity can be defined that is protective against a positive energy imbalance, and hence weight gain.

Measuring physical activity

306. Studies investigating physical activity have employed either subjective measures, based on self-report and questionnaires, or objective measures, based on measures of physiological response (e.g. heart rate) or bodily movement (e.g. accelerometers). PAEE has been measured using the DLW technique.

Subjective measures of physical activity

307. Many types of physical activity questionnaires have been used in surveys and epidemiological studies; these can be global, single item or comprehensive in design. The questionnaires can be self administered or completed by an interviewer. Information obtained is often converted into a summary measure that is then used to categorise or rank the physical activity level of subjects. Questionnaires can detail physical activities performed during a specified period, but their accuracy is limited, especially in assessing non-exercise physical activity [354].

308. Children are less likely than adults to make an accurate self-reported physical activity assessment [355] and in children of younger age groups it is virtually impossible to obtain valid self-reported physical activity data [356].

309. Even when physical activity questionnaires are logically constructed with attention to the different domains of activity, they are still relatively imprecise as a measure of PAEE [357]. In adults, subjective measures of physical activity have proved sufficient to demonstrate associations with many disease outcomes and have allowed the estimation of dose-response effects, but objective methods are more accurate and allow more precise estimations of dose-response effects. It has been suggested that many physical activity questionnaires have an arbitrary grading in their classification of relative activities, which can result in an overestimation [146].

310. The use of objective measures of physical activity is required to elucidate the dose-response relationship between physical activity and health, in addition to determining current levels of physical activity, monitoring compliance with physical activity guidelines and

determining the effectiveness of intervention programmes designed to improve physical activity.

Objective measures of physical activity

311. Some studies have used measures of cardiorespiratory fitness as a proxy for physical activity and have generally shown stronger associations with health outcomes than studies with self-reported physical activity as the exposure. Cardiorespiratory fitness can be improved in a dose-response fashion by exercise training [358;359], however, measures of cardiorespiratory fitness do not describe the amounts and types of physical activity or the amount of energy expenditure associated with decreased disease risk [358]; they may also be influenced by other environmental and genetic factors [360]. In children, there is only a weak association between cardiorespiratory fitness and the level of physical activity [361]. In relation to health outcomes, the level of physical activity appears to act independently of cardiorespiratory fitness, e.g. objectively measured physical activity has been associated with individual and clustered metabolic risk factors independently of cardiorespiratory fitness [362-364]. Studies measuring cardiorespiratory fitness as a surrogate for physical activity have not been included in this Appendix.

312. The DLW method measures TEE over several days and in conjunction with measures, or estimates, of BMR/RMR can be used to measure PAEE indirectly. The DLW method is considered the gold standard for measuring energy expenditure under free-living conditions. It does not, however, give day-to-day information nor does it give information on the forms, frequency and intensity of physical activity undertaken [356].

313. Techniques such as heart rate monitoring (HRM) and accelerometry provide minute-by-minute data and give information on the total levels of physical activity, as well as the intensity, duration and frequency. Accelerometry measures body movement – usually in one (vertical) or three (vertical, lateral and anterior-posterior) planes – but is limited in its ability to measure activities such as swimming and cycling. By applying movement count cut-off points, minute-by-minute data from accelerometers can be summated into time spent in low-moderate- and vigorous-intensity activity. There is uncertainty, however, in defining cut-offs for different intensity levels, which causes problems when comparing studies [365;366]. The HRM method is limited in its ability to differentiate between modest increases in heart rate (HR) above resting levels and increases in HR associated with stress or other causes. The combining of HRM with movement sensors addresses these issues and improves accuracy [356]. PAEE can be estimated in groups using HRM and accelerometry [367], but the DLW method provides a more accurate assessment.

Assessment of physical activity levels in the UK population

314. The NDNS of adults aged 19-64 years (2000/1) was the first of the NDNS series to collect data on physical activity [7]. Following this, the 2007 Low Income Diet and Nutrition Survey (LIDNS) collected information on physical activity and the National Health Surveys also report on physical activity data. The Health Surveys use a seven-day recall method to assess physical activity, while the NDNS uses a seven-day diary; activities lasting less than 15 minutes were excluded in the Health Surveys, while activities lasting less than 10 minutes were excluded in the NDNS.

315. Both the NDNS and the Health Surveys provide estimates of physical activity as the

proportion of the survey population who report achieving physical activity recommendations, but these are based on self-reported physical activity and accuracy, therefore, is limited. The NDNS also provides estimates of population PAL values.

316. In the UK, adults are recommended to have at least 30 minutes of moderate intensity physical activity (similar to brisk walking) on five or more days of the week. It is also recommended that, for many people, it is likely that 45-60 minutes of moderate intensity physical activity a day would be needed to prevent obesity [368]. For children and young people, a total of at least 60 minutes each day of at least moderate intensity physical activity is recommended, and at least twice a week this should include activities to improve bone health (activities that produce high physical stresses on the bones), muscle strength and flexibility.

317. In the NDNS of adults aged 19-64 years (2000/1), 36% of men and 26% of women reported spending 30 minutes or more per day in activities of at least moderate intensity on five or more days. For men, the proportion who reported achieving the physical activity recommendation decreased with age, whereas, for women, there were no significant age differences (see Table 27).

Table 27. The proportion of adults aged 19-64 achieving the physical activity target, 2000/1, by age and sex in the NDNS[7]

	Age				Total
	19-24	25-34	35-49	50-64	
	%	%	%	%	%
Men	49	46	34	24	36
Women	29	30	25	22	26
Base					
Men	104	211	243	243	801
Women	100	202	305	249	857

318. The LIDNS [9] showed 11% of men and 8% of women reported spending 30 minutes or more per day in activities of at least moderate intensity on five or more days. This was substantially less than the proportions reporting meeting the physical activity guidelines in the NDNS.

319. The Health Survey for England (HSE) reports on physical activity data collected since 1997 [369]. In 2006, 14,145 completed questionnaires were obtained from respondents, 6,845 men and 7,300 women; 40% of men and 28% of women reported achieving the physical activity recommendations for adults (see Table 28).

320. Regression analysis in HSE 2006 found that both men and women with low activity levels were around twice as likely to have a raised waist circumference compared to those with high activity levels (odds ratios of 2.1 and 1.9 respectively).

321. The Scottish Health Survey 2003 (2005), the Welsh Health Survey 2003/04 (2005) and the Northern Ireland Health and Social Wellbeing Survey 2001 (2001) detail the proportion of adults who have reported achieving the physical activity recommendations. In Scotland, this was 42% men and 30% of women; in Wales 36% of men and 23% of women; and in Northern Ireland 30% of men and 26% of women.

Table 28. Proportion of adults aged 16 and over achieving the physical activity target in 2006 by age and sex in the HSE[370]

	Age							Total
	16-24	25-34	35-44	45-54	55-64	65-74	75+	
	%	%	%	%	%	%	%	%
Men 2006	53	52	46	38	35	21	9	40
Women 2006	33	36	35	34	27	16	4	28
Base								
Men 2006	1040	1127	1354	1122	1012	694	496	6845
Women 2006	1011	1157	1375	1141	1050	768	798	7300

322. The HSE 2007, shows 72% of boys and 63% of girls report meeting current physical activity guidelines for children (achieving 60 minutes or more of at least moderate intensity

physical activity a day) [371]. The 2003 Scottish Health Survey [83] showed that 74% of boys and 63% of girls aged 2-15 years reported achieving physical activity guidelines. The Welsh and Northern Ireland Health Surveys only collected data from adults aged at least 16 years of age.

323. The LIDNS [9] observed that children from low income families reported lower levels of physical activity. Twenty-six percent of boys and 31% of girls aged 2-10 years and 34% of boys and 38% of girls aged 11-15 years achieved the recommended 60 minutes of physical activity on all 7 days of the week. Furthermore, 52% of boys and 49% of girls aged 2-10 years, and 28% of boys and 41% of girls aged 11-15 years were active for less than 30 minutes every day on average.

324. Self-report methods, such as questionnaires, are impractical in children because they are likely to be inaccurate [372]. Objective measures overcome some of the problems of measuring physical activity in children; as a result, accelerometry-based physical activity monitors have been increasingly employed as a means of assessing physical activity in children.

325. Physical activity has been objectively measured, using accelerometry, in 5,595 UK children [373]. The median time spent in moderate to vigorous physical activity in this study was 20 minutes per day (boys, 25 minutes per day; girls, 16 minutes per day) and there was substantial intra-individual variation in the measured physical activity of these children [372]. Overall, only 5.1% of boys and 0.5% of girls achieved the current recommended level of activity, which is much lower than the HSE estimate. These figures were also lower than those reported for European [374] and North American children [375], but these differences may be caused by the use of different cut-points of accelerometer counts to define the lower threshold of moderate-intensity activity.

326. A further UK study, however, in 2,064 children found the mean time spent in moderate to vigorous physical activity to be 84 minutes per day for boys and 66 minutes per day for girls [376]. This study indicates that almost 70% of children meet national physical activity guidelines. The different findings to the previous study [373] are explained by the different thresholds used to define moderate to vigorous physical activity.

327. Children from a deprived inner city British school were also shown to be physically active, as assessed by accelerometry, at recommended levels and had similar levels of activity to children in other studies from more affluent populations [377]. When another established cut-off point was used to define physical activity intensity, however, only 7% of children were defined as achieving the recommendation.

328. A comparison of the parent-reported physical activity questionnaire used in the HSE with concurrent 7-day accelerometry data in 130 children aged 6-7 years of age, found that the questionnaire over-estimated moderate–vigorous intensity physical activity [378]. The estimated mean time spent in moderate–vigorous intensity physical activity was 146 min/day (95% CI 124 to 169) using the questionnaire and 24 min/day (95% CI 22 to 26) using the accelerometer. Overall, accelerometry studies are dependent on the threshold used to define moderate to vigorous physical activity, but some show much lower levels of physical activity in children than suggested by questionnaire data.

UK population PAL values

329. It was not possible to derive PAL values from the Health Surveys because they do not record the amount of reported time spent on all types of activity. PAL values for adults aged 19-64 years were derived from the seven-day physical activity questionnaire in the NDNS (see Table 3); BMR was calculated using the modified Schofield equations [1]. No survey data of PAL values for children and adolescents are available.

330. An unpublished validation study for the seven-day physical activity questionnaire was conducted prior to the main adult survey in a sample of 66 adults [379]. This study included a DLW assessment of energy expenditure as well as dietary and activity records. The mean PAL values derived by the two methods were similar at around 1.8 for men and 1.7 for women; however, the correlation between the individual PAL values derived from DLW measurements and from activity records, for the 60 individuals who took part in all components of the validation study, was weak and did not reach statistical significance.

Table 29. PAL values for adults aged 19-64 years derived from seven-day physical activity questionnaire in the NDNS[7]

	Age				Total
	19-24	25-34	35-49	50-64	
Men					
Mean PAL	1.93	1.94	1.86	1.77	1.85
No of subjects	54	144	283	216	697
Women					
Mean PAL	1.72	1.71	1.72	1.66	1.70
No of subjects	66	187	341	260	854

331. It is very difficult to compare or correlate self-reported physical activity data with objectively measured movement or DLW data, as each measures different dimensions of physical activity. It would not necessarily be expected, therefore, that there would be much agreement between these methodologies, e.g. a comparison of 20 physical activity questionnaires with DLW measures failed to demonstrate the validity of the questionnaires for PAEE estimation [380].

332. Considering that only 36% of men and 26% of women report meeting the 30 minute physical activity recommendation, the NDNS PAL values based on the activity records seem high, although mean PAL values are in agreement with those derived from the validation study. The PAL values obtained from the NDNS, an average of 1.85 for men and 1.70 for women, are for fairly active people. Moderate intensity activity of approximately 45 to 60 minutes per day has been suggested to correspond to an approximate PAL value of 1.7 [381].

333. The discrepancy between the PAL values and the percentage meeting the physical activity recommendation could be due to relatively light physical activities that were recorded and contributed to PAL, but not to achieving the physical activity recommendation. The NDNS questionnaire methodology is thought to overestimate physical activity in people

with low activity levels.

Summary

334. The assessment of physical activity levels in the UK, i.e. the Health Surveys and the NDNS and LIDNS, is dependent upon subjective measures of physical activity, which do not give an accurate representation of habitual levels. It is likely that these give an overestimation of physical activity in the population. To enable the accurate determination of habitual physical activity levels in the UK population surveys need to employ objective measures of the intensity and duration of physical activities.

Temporal trends in physical activity in the UK

335. In the UK, there is no dedicated surveillance system for population-level physical activity to enable the elucidation of patterns and trends in physical activity at the national level. The information that is available on population-level physical activity trends mostly stems from ecological proxy domain-specific measures [106]. For example, there has been a massive reduction in the proportion of the workforce employed in manufacturing, farming and other physically-demanding occupations; car ownership has increased; and the distance children and adults walk or cycle per year has declined [382]. It could be that the apparent temporal changes in activity in domestic life, work and travel are compensated for by an increase in recreational activity, but this information is not available for the UK.

336. In 2005, the three main activities of men and women in Great Britain were sleeping, working in their main job and watching television and videos/DVDs or listening to music [383]. The *Time Use Survey* observed that people were less likely to spend time on housework in 2005 than in 2000, but, generally, the pattern of time use was very similar between 2005 and 2000.

337. The HSE has been collecting multiple-domain physical activity data since 1991. An analysis of this data was performed to estimate temporal trends of participation in physical activity between1991 to 2004 [384], a period when the prevalence of obesity in adults living in England rose by over 65% [382]. The study found a consistent upward trend for regular participation and time spent in sports, but a decline in occupational physical activity between 1991/2 and 2004 in both men (43.4% to 38.5% active in work) and women (27.3% to 24.7% active in work). The decrease in reported high physical activity levels at work was more pronounced from 1998 and onwards. Increases in time spent in sports were evident in all age groups, but particularly pronounced among the middle and late life age groups (aged 35 to 49 and older).

338. The data were deemed insufficient, however, to provide a definitive answer as to whether overall physical activity has changed between 1991 and 2004. Fluctuations in time spent at moderate to vigorous physical activity and the percentage of men and women meeting the physical activity recommendations were more likely a function of changes in the questions included in different surveys and the imposition of certain analytical assumptions these changes forced, rather than a reflection of true changes in the physical activity levels of the population [384]. It was concluded that there is an urgent need for a carefully designed UK physical activity surveillance system that includes objective measures of physical activity.

339. The 2006 HSE reports on trends in physical activity [385] from 1997, 1998, 2003, 2004 and

2006 and observed a further increase from 2004, for both men and women, in the proportion reporting achieving physical activity recommendations, from 32% in 1997 to 40% in 2006 for men and from 21% to 28% for women.

340. The 2007 HSE report also shows the proportion of boys and girls reporting achieving the physical activity recommendations were similar in 2002 and 2007. The Health Behaviour in School-aged Children study (a WHO cross-national survey) of 11-, 13- and 15-year-old schoolchildren has been carried out in Scotland and Wales since 1986 at four-yearly intervals [386]. In Scotland and Wales, there was an increase in the percentage of schoolchildren who reported undertaking vigorous physical activity at least four times a week between 1985/86 and 1997/98, followed by a decline in 2001/02. The proportions reporting watching 4 hours of television daily changed little between 1985/86 and 1997/98.

341. In healthy subjects from Holland (n=366) and North America (n=393) PAEE (evaluated from TEE measured using doubly labelled water and BMR by calorimetry) was determined at various time points between 1988 and 2005 [387]. In both the Dutch and North American subjects PAEE and PAL did not decrease over the time period, a period in which the prevalence of overweight and obesity has increased in both populations. This suggests that a reduction in PAEE is unlikely to have fuelled the obesity epidemic.

Sedentary behaviour and weight gain

342. Sedentary behaviour is a different concept to physical activity with a different physiology and different determinants. Many behaviours are largely sedentary, including listening to the radio or music, watching television, playing digital or board games, using computers and reading.

343. It has been suggested that the increased use of information and communication technology, particularly watching television, playing digital games and using computers are sedentary factors affecting obesity prevalence [388;389]. The use of computers, both at home and at work, has been one of the most rapidly expanding activities in the past 20 years and could potentially impact on overall physical activity levels; equally, computer use could have replaced time spent in other sedentary activities.

344. A meta-analysis has been conducted of prospective studies and trials investigating the relation between television viewing and video/computer game use and body fatness and physical activity in children and adolescents [390]. The only significant relationship observed was between television viewing and body fatness, but it was concluded that this was likely to be too small to be of substantial clinical relevance and that media-based inactivity may be unfairly implicated in recent epidemiologic trends of overweight and obesity among children and adolescents. It was also noted that relationships between sedentary behaviour and health were unlikely to be explained using single markers of inactivity, such as television viewing or video/computer game use. Physical activity and sedentary behaviours are regulated through a complex series of decision-making mechanisms and restricting television viewing alone may not be effective in increasing physical activity [391].

345. Several prospective studies conducted since the meta-analysis have also observed positive associations between television viewing in children and subsequent weight gain [392-398]. It has been suggested that although the effect size appears small for time spent watching television as a predictor of weight gain in childhood, it is larger than the effect sizes

commonly reported for dietary intake and physical activity; thus, television viewing could be an important contributing factor to childhood obesity [395].

346. The issue of measurement error in these studies and the need to select measures of television viewing that are valid and reliable, to examine with greater accuracy the influence of television viewing on childhood overweight, has been highlighted [399].

347. A prospective study of adolescents in the US, observed that changes in television viewing were not associated with changes in leisure-time moderate/vigorous physical activity [400]. It was suggested that television viewing and leisure-time physical activity were separate constructs that could each affect weight gain, but were not functional opposites. Television viewing may be related to overweight through television's effects on dietary intake; television advertising may promote consumption of unhealthy foods [401;402] and people tend to snack while watching television [403-405].

348. Most studies examining the prospective and longitudinal associations between sedentary behaviour and BMI have relied on self-reported data. One prospective population-based cohort study measured sedentary behaviour by individually calibrated heart rate monitoring in 393 healthy adults [406]. At 5.6 years follow-up, sedentary time did not predict any of the obesity indicators (body weight, BMI, fat mass and waist circumference); however, the obesity indicators predicted sedentary time at follow-up after adjustment.

349. A systematic review has been conducted of trials to reduce sedentary behaviour among children, either alone or in combination with other health messages [407]. The interventions ranged from 4 weeks to 4 years, with six of the studies targeting clinic-based populations that were overweight or at risk of overweight. A further six were population-based prevention studies. The magnitude of change in weight parameters was modest and was difficult to interpret, as normal BMI ranges vary with age and development in children. The z-BMI (BMI normalised to age and sex) was only reported in a few of the studies. Virtually all of the interventions, however, consistently resulted in slowing of the increase in the subjects' BMI relative to similar aged controls. As the sedentary behaviour messages in these interventions are often combined with other health information (e.g. healthy eating and exercise), it was not possible to estimate the magnitude of the weight influences due to sedentary behaviour messages alone.

Physical activity and body fatness

350. Physical activity has long been considered an integral component in the treatment of those who are obese and in the prevention of weight regain in those who have lost weight [408-410]. Physical activity alone appears a relatively inefficient means for losing weight, but appears to be an important factor in the successful maintenance of weight loss and in improving insulin sensitivity and cardiovascular health [409;411-413].

351. The focus of this section is on the role of physical activity in the primary prevention of weight gain and obesity.

Prospective studies of self-reported physical activity and weight gain

352. The prospective studies relating physical activity and weight change were systematically reviewed in 2000 both in adults and children [414;415]; this was subsequently updated by a

systematic review of prospective cohort studies and trials published since 2000, which examined the association between physical activity and weight change in adults and children [106].

Adults

353. The Fogelholm and Kukkonen-Harjula (2000) systematic review included 16 prospective studies investigating the relationship between self-reported physical activity and weight change. The mean duration of the follow-up was approximately 7 years, with a range from 2 to 21 years. The number of participants ranged from 210 to 79,236. All studies used a retrospective questionnaire to assess the habitual level of physical activity. The studies differed in the physical activity data that was collected, i.e. whether baseline, follow-up or change in physical activity compared to weight change.

354. Overall, two studies reported a consistent inverse association between baseline physical activity and subsequent weight gain [416;417]; three found no effect [418-420] and one found a positive association [421]. One study observed a positive association for men and a negative association for women between baseline physical activity and subsequent weight gain [422]. Jogging or running, but not other less strenuous activities, were inversely associated with weight gain in one study [423].

355. There were seven studies that found an increase in physical activity between baseline and follow-up was associated with less weight gain [416;417;420;424-427] and two observed no association [418;421]. Four studies found that a large volume of physical activity at follow-up was associated with less weight gain [417;420;428;429], while one did not [430]. In one study the cumulative duration of increased physical activity was observed not to be associated with weight change [431].

356. It was concluded that there was inconsistent evidence of a predictive effect of physical activity at baseline being associated with less weight gain over time. The association between weight gain and change in activity was observed to be stronger, although still modest [414].

357. A follow-up systematic review [106] included twelve prospective studies investigating the relationship between self-reported physical activity and weight change. Most studies included a large range of subjects (539 to 50,277) and a range of follow-up from 3 to 11 years. Nine studies reported a negative association between baseline physical activity and subsequent weight gain [432-440] and two found no association [441;442]. One study reported an inverse association suggesting higher baseline levels of BMI predicted physical inactivity [443]. The majority of studies suggested that low levels of physical activity were associated with future weight gain, but the effect size was small. The more recent studies included in this review had no studies with less than 500 participants, whereas the studies included in the previous review [414] included five studies with less than 500 participants and, therefore, less power to detect small differences. Improvements in study design could also be a factor, as could publication bias in determining why the follow-up systematic review produced more consistent results.

358. It was concluded that in longitudinal cohort studies, individuals who reported higher levels of leisure-time physical activity tended to be less likely to gain weight, but studies varied in their conclusions because of issues of confounding, measurement error and reverse

causality, i.e. obesity may lead to physical inactivity [443].

359. Two studies, which reported subsequent to the systematic review, observed leisure-time physical activity to be inversely associated with BMI, especially in women [444], and waist circumference [445], While a study in women found leisure-time walking to be inversely associated with weight gain, particularly in those with a larger baseline weight [446].

Children and adolescents

360. The Molnar and Livingstone systematic review identified two prospective studies [415] that investigated the influence of self-reported physical activity on the change in relative BMI. One study found increases in children's leisure activity at follow-up to be associated with decreases in subsequent weight gain [447], while the other found no association [448].

361. The Wareham *et al* (2005) systematic review identified a further 11 studies with a follow-up ranging from 1 to 23 years; five of the studies had a follow-up of 2 years or less. The studies included between 59 and 11,887 children, with four including more than 1000 children. Most studies included children less than 10 years old; the range was 3 to 14 years. All studies, except one [449], used reported change in BMI or sum of skinfolds as the outcome. Five of the studies did not observe an association between physical activity or sedentary behaviour and weight gain [450-452;452;453]. The other six studies found an inverse association between higher levels of physical activity and weight gain or a positive association with sedentary activities [394;449;454-458].

362. Overall, the results were mixed and it was concluded that, as in the adult studies, the measures of association tended to be small [106]. Another review of prospective studies also concluded that the results were mixed and that the associations identified were generally of a small magnitude [459].

363. Of the studies that have reported subsequent to the review, two studies [460;461] have observed physical activity to attenuate increases in fat mass development in boys, but not in girls [461]. One observed no difference in BMI changes or the percentage of students classified as obese between school with higher and lower frequency of physical education [462]. Another observed reported physical activity and inactivity to be related to accrual of body fat, particularly among children with at least one overweight parent [463].

364. Most obese children remain obese as adults [464] a progression that is referred to as 'tracking' of overweight. Several studies have examined whether adolescent physical activity affects subsequent weight gain through to adulthood. Some prospective studies do provide evidence that a decline in reported physical activity between adolescence and adulthood may increase risk of weight gain and obesity, but these associations are generally weak and inconsistent [449;465-471].

365. On balance, the available evidence from prospective cohort studies suggests that increased physical activity and decreased sedentary behaviour may be protective against relative weight and fatness gains; however, the results are mixed and the associations that are identified are generally of a small magnitude. It is likely that imprecise measurement of activity exposures weakens the observed relationships [459]. Measurement error is probably an important factor as most studies rely on subjective measures of reported physical activity and assess fatness using BMI, which is limited in its ability to determine fat and lean tissue mass

across the normal range in adults [72] and children [472].

Cross-sectional studies of objectively measured physical activity and weight gain

366. Due to the unreliability of self-reported physical activity, especially in children, and the paucity of prospective studies with objective measures, cross-sectional studies of objectively measured physical activity or PAEE and body fatness are considered below.

Adults

367. Several studies have compiled data sets of DLW measures of TEE to examine the relationship between energy expenditure and body fatness [108;186;473]. These studies found that in males there was an inverse cross-sectional relationship between PAEE, PAL and percentage body fat, but in females no such relationship was apparent.

368. A case-control study observed accelerometry assessed physical activity in obese adults was strongly associated with BMI [474]; this association was observed for total and all intensity levels of physical activity. In the non-obese adults, however, only a weak inverse association with vigorous-intensity physical activity was observed.

Children and adolescents

369. Several studies have assessed the relationship between PAEE and body fatness in children and adolescents. While some studies have reported an inverse association between measures of energy expended [475-482], just as many others have reported no association [483-490].

370. In one case-control study, obese adolescents were less physically active (as determined by accelerometry) than normal-weight adolescents, but PAEE was not different between the groups [476]. Percentage body fat was negatively associated with PAL in the two groups combined, but there was no difference in PAL or PAEE between obese and non-obese adolescents after adjustment for body composition. The differences in physical activity between the groups, which were not reflected in any differences in TEE and PAEE, could be explained by the increased energy cost of moving a larger body mass: the absolute energy expenditures while walking at 4 and 6 km/h were 35% higher in the obese group.

371. One other study to concurrently measure PAEE, using the DLW method, and physical activity, by accelerometry, in non-obese children, found body fat and BMI to be inversely correlated with PAL. Time spent in vigorous activities was inversely correlated to percentage body fat, but not BMI, which was stronger than the correlation between body fat and PAL [475].

372. Both these studies also appear to identify an approximate threshold above which lower measures of body fatness were observed: 125 minutes vigorous-intensity activity/day [475] and 120 minutes moderate-vigorous-intensity activity/day [476].

373. Most studies have found inverse associations between moderate to vigorous- or vigorous-intensity activity (as assessed by accelerometry) and measures of body fatness [475;491-501], but not all [502;503]. One study observed an inverse relationship between vigorous-intensity activity and waist circumference, which was also positively related to inactivity, in boys, but not girls [504]. Other studies have reported null associations between low-intensity activity and

measures of body fatness [476;494;498].

374. Total physical activity, as assessed by accelerometry, was not found to be associated with variance in body fat in several other studies [494;499;502], but, in one other study, the sum of four skinfolds, but not BMI or waist circumference, was inversely correlated with total physical activity [505]. In children at risk of obesity (>75th BMI percentile), accelerometer-measured total physical activity was an independent correlate of the children's visceral fat, with greater physical activity being associated with lower fat accumulation in this depot. The association between physical activity and visceral fat was maintained after adjusting for the relationship between whole-body fat and visceral fat and for a negative association between physical activity and whole-body fat [506].

375. Accelerometry studies have observed obese children and adolescents to be less physically active overall than their non-obese counterparts [476;507-510]. One study observed activity levels in overweight and obese children to be lower than normal weight children, but the precise nature of the relationship appeared to differ between boys and girls [373].

376. The lack of a consistent association between DLW-derived measures of PAEE, PAL and measures of body fatness could reflect the different energy costs of certain physical activities, such as weight-bearing activities of moderate to vigorous intensities (e.g. walking and running), that are not independent of body weight or FFM [511].

377. Although the use of PAL adjusts, to some extent, for body weight and composition (by using BMR or RMR), it is not necessarily independent of body weight or FFM [512;513], particularly in weight bearing activities of moderate to vigorous intensity. Heavier individuals, therefore, may have a higher PAL as a result of their larger body mass [356].

378. The accelerometry studies in children suggest, to some extent, that the intensity rather than the total amount of physical activity may be more important in relation to the prevention of obesity in children; however, it is difficult to infer a causal relationship, and it is impossible to determine its direction from cross-sectional data. It is unclear whether the physical activity variable is a predictor or an effect of the individual's weight status. As accelerometry measures movement, not energy expenditure, it is possible that differences in activity as recorded by the accelerometer may not reflect differences in energy expenditure, as heavier children have more weight to move. Prospective studies are required to confirm the relationships observed in cross-sectional accelerometry studies.

Prospective studies of objectively measured physical activity and weight gain

Adults

379. No relevant studies were identified in the Fogelholm and Kukkonen-Harjula (2000) systematic review, but the Wareham *et al* (2005) systematic review[121] identified two studies. In Pima Indians (n=92), PAEE, as determined by the DLW technique, was found not to be associated with change in body weight at follow-up after 4 years [514]. In a population cohort of UK adults (n=739), the association between PAEE, as assessed using HRM, and change in body composition (FM and FFM) over a 5.6 year median follow-up period was investigated [515]. Baseline PAEE was inversely associated with FM in younger adults (aged less than 53.8 years), but not older adults (aged more than 53.8 years), although the effect size was small. On average, younger adults gained weight during the study. In older adults, who were

generally weight stable, baseline PAEE was inversely associated with gain in body weight (an increase both in FM and FFM).

380. A later study [516] of obese (n=13) and normal weight (n=15) young adults followed-up for 4 years, assessed TEE and PAEE by DLW, and physical activity by accelerometry in relation to change in body weight and FM. Energy expenditure estimates and subcomponents of physical activity (i.e. time spent at different intensity levels) were not significantly associated with change in body weight or FM, but change in overall physical activity (as assessed by accelerometry) was inversely associated with change in body weight and FM. *Post hoc* analyses suggested that this association was explained by changes in the normal weight group only, suggesting that the observed association may differ depending on weight status.

381. In African Americans (n=172) and Nigerians (n=149), PAEE, as determined by DLW technique, was found not to be associated with change in body weight at follow-up after 3 years [517].

Children and adolescents

382. The Molnar and Livingstone systematic review identified five prospective studies [415] that investigated the association between objectively measured physical activity or PAEE and change in indices of body fatness in children and adolescents.

383. One study observed children with low levels of physical activity (assessed using accelerometry) to gain substantially more subcutaneous fat than more active children [518]. Three studies used DLW techniques to assess energy expenditure. While one small study observed reduced TEE, and particularly PAEE, to be associated with weight gain [519], other, larger studies have found no association [520;521].

384. The Wareham *et al* (2005) systematic review[121] identified five subsequent studies. The children included in these studies were mostly younger than 10 years and the duration of follow-up ranged from 2 to 8 years.

385. One study found increased physical activity, assessed using accelerometry, to be associated with smaller gains in BMI and subcutaneous fat [522]. The other studies used DLW techniques to assess energy expenditure [523-526], but overall the results were inconsistent.

386. Studies in overweight Pima Indian children [527] and adults [514] were not included in the systematic review. These studies measured TEE and PAEE using DLW techniques and observed no relationship with changes in body weight.

387. Several studies have been published since the review. One found no association of PAEE (or other TEE variables determined by DLW techniques) with relative weight and percentage FM during adolescence [528]. The other studies have used accelerometry to assess physical activity [493;529-532] and while some have found associations with weight gain the results are, overall, mixed. Most studies found no association between moderate-vigorous physical activity and weight gain. One study assessed physical activity by HRM, but also found inconsistent associations [396].

388. Overall, the results from prospective studies using objective measures of physical activity in children, adolescences and adults were mixed and the associations identified were

generally of small magnitude [106;459]. For example, the degree of variance in BMI attributed to physical activity in several studies was less than one percent [494;533].

389. The lack of consistent associations between DLW-derived measures of PAEE and measures of body fatness could be interpreted as evidence that energy intake is a more important determinant of excess fat mass gain. There are difficulties in the interpretation of these data, however, because of the controversy regarding the means of comparing TEE and PAEE among individuals of different sizes [534]. It has been suggested that when studies evaluate associations between PAEE or PAL and percentage body fat, the differences between energy expended in physical activity are likely to be overestimated between leaner and fatter children and the differences in body fatness underestimated, resulting in associations being biased towards null [356]. The use of DLW measures to identify how much PAEE is necessary to prevent obesity is complex; even if appropriate adjustment for body composition is made, comparisons between populations are difficult. It is also important to note that the energy expended in activity may not be the same as the amount of physical activity required to prevent excess FM gain; thus, assessment of physical activity by methods such as HRM and accelerometry is also required [356].

390. The potential impact of exercise intensity on change in body weight and FM remains unclear [535-538] and it is not known which, if any, of the subcomponents of free-living physical activity contributes more to change in body weight and FM.

Trials to prevent weight gain

391. Interventions aimed at weight reduction or at preventing weight regain are not included in this consideration. A systematic review was published in 2000 that identified nine interventions (eleven publications) of the primary prevention of weight gain [539]. Interventions lasted from 6 weeks to 36 months. Four interventions took place in the community [540-544] and five were school based [545-550].

392. It was concluded that overall the results suggested mixed effects and, for various methodological reasons, they were uncertain in their conclusions about whether increasing physical activity was effective in preventing weight gain. Effectiveness appeared to be greater among older, male and high-income participants, and lower among low-income participants, school students and smokers. Where diet and physical activity were described, positive effects were usually obtained, but the validity of this was limited as they were measured by self-report.

393. This systematic review was subsequently updated with a further seventeen trials in 2005 [106]. A total of six trials aimed at increasing physical activity and preventing weight gain in adults were identified. The interventions took place in populations at risk of weight gain or in whom a public health intervention might be targeted. Interventions lasted from 12 weeks to 5 years. In the four trials where differences in body composition between intervention and control group were observed, two found an increase in body weight in the control group and weight stability in the intervention group [551;552], one found a weight reduction in the intervention group [553] and the other observed decreases in both groups [554]. Two trials observed no effect on weight gain [555;556].

394. A total of eleven trials were identified in children aimed at preventing unhealthy weight gain by increasing physical activity or reducing sedentary behaviour. Nine trials were

school-based and the others home or family-based. Interventions lasted from 12 weeks to 3 years. Three of the trials reported a small intervention effect at follow-up [557-559], with two of them reporting effects in boys only [557;559]. The other eight trials reported no significant effects on body weight or composition at follow-up [560-567].

395. It was concluded that there were still relatively few trials aimed at the primary prevention of weight gain and that there was still insufficient evidence on which to base conclusions about which of the approaches were effective [106]

396. Two trials have reported subsequent to the review. While one found a nursery and home-based intervention to increase physical activity did not reduce BMI [568], the other found a school-based intervention did decrease gain in BMI, especially in non-overweight adolescents [569]

397. Relatively few trials aimed at the primary prevention of weight gain were identified. Overall, findings from these were inconsistent.

Summary

398. The assessment of UK population physical activity levels, i.e. the Health Surveys and the NDNS and LIDNS, is currently dependent upon subjective measures of physical activity. It is likely that these give an overestimation of physical activity in the population, e.g. the NDNS 2000/1 for adults estimates a mean PAL value of about 1.8 for men and 1.7 for women. To enable the accurate determination of habitual physical activity and PAEE in the UK population surveys need to employ objective measures.

399. Methodological constraints are a severe limitation in defining the role of physical activity in the regulation of body weight. Most studies rely on subjective measures of reported physical activity and assess fatness using BMI, which is of limited value in determining fat and lean tissue mass across the normal range in adults [72] and children [472]. Error is introduced on both sides of the relationship reducing the ability to detect any change. The application of more precise methods for the measurement of physical activity and body fatness is required to define their interrelationship.

400. On balance, the available evidence from prospective cohort studies suggests that increased leisure time physical activity may be protective against relative weight and fatness gains; however, the results are mixed and the associations that are identified are generally of a small magnitude. Prospective studies also suggest lengthy television watching may be a predictor for weight gain, but again the associations are weak and inconsistent. Evidence from studies employing objective measures of PAEE and trials of the primary prevention of weight gain is inconsistent.

401. The issue of whether there is a specific level of physical activity required to prevent unhealthy weight gain is very complex, and available data is insufficient for a definitive conclusion [106;358]. As weight gain is dependent on energy intake, consideration of energy balance and flux is required. This is the topic of Appendix 7.

Appendix 6. Energy requirements for Illness

Introduction

402. There is a continuum in physical function between health and disease, but the dividing line between them can be difficult to define. The proportion of older individuals in the population is increasing in the UK [570] and the incidence of many diseases and disabilities also increases with age [137]. In the 2001 UK General Household Survey, one in ten respondents under the age of 45 years reported a longstanding illness that limited physical activity, compared with a third of older respondents [570]. Less severe disabilities may produce effects on physical activity that are difficult to distinguish from normal activity. The prevalence of disease in older subjects is common making it is difficult to define 'normal', especially in extreme old age. A consideration of PAL values in older adults is given in Chapter 3.

403. Assessing the energy requirements of patients with acute and chronic diseases is more complex than for those in good health. These requirements not only depend on the aggressiveness of the disease and level of inactivity it causes, but also on the treatment, and the presence of prior malnutrition. It used to be thought that the energy requirements of a number of severe acute diseases were increased [571]. The energy requirements of individuals with spastic disorders, such as spastic cerebral palsy [572], were also thought to be raised. It is now understood that this is not usually the case.

404. The energy requirements of sick people are greatly influenced by the type (acute or chronic), severity, and phase of the disease (acute or recovery phase). They are also affected by the presence of other physical and psychological disabilities, which may vary over time, and the nutritional state of the patient. Sometimes it may not be appropriate to treat the disease or the associated malnutrition, as when a patient is approaching death and feeding is a burden.

Energy intake

405. Subjects with disease may be in substantial energy imbalance for days, weeks, and sometimes months. This imbalance is often caused by anorexia, which is a common consequence of traumatic, infective, malignant or other inflammatory diseases. Clearly, accurate measurements of energy intake in disease do not necessarily reflect the energy required to maintain energy balance or the energy required to achieve optimal health. Furthermore, although in undernourished subjects, additional energy is required for repletion and improvement in tissue function, health and well being, the reverse applies to obese individuals. If absorption of nutrients is reduced due to illness or urinary losses occur, e.g. in diabetes, then the nutritional value of ingested foods will be less than in an unaffected individual.

406. The timing of nutritional support is also important. Aggressive overfeeding in the acute phase of injury, for example, can cause metabolic disturbances, such as hyperglycaemia (diabetes of injury) and increased CO_2 production, which can be detrimental to patients with respiratory failure. In contrast, very slow repletion during recovery can prolong the period of ill health, as well as poor work performance and poor quality of life. Finally, nutritional intake in disease may differ from health in that it can be provided artificially using an enteral

tube or venous catheter (sometimes for life), independent of the appetite.

Energy expenditure

407. BMR is more variable in disease than in health. Apart from being influenced by the type, severity, and phase of the illness, BMR is also influenced by the nutritional status of the patient and a wide range of treatments, which may vary from surgical interventions, immobilisation, and artificial ventilation to blood transfusions and drug therapy. Standard reference tables or equations for predicting BMR from weight, height and age, were established for use in healthy subjects without malnutrition and disease, and without dehydration and oedema, which can have substantial effects on body weight. The prediction of BMR, therefore, is more likely to be in error in disease than in health.

408. Whether measurements of TEE (or measurements of BMR) are regarded as normal or abnormal, relative to a healthy group, may depend on the way in which the results are expressed. This can be problematic for patients with disease with abnormal body composition and body proportions, who preferentially lose or preserve particular tissues or organs (e.g. muscle wasting in certain neurological conditions). Over 20 indices that have been used by different workers to express energy expenditure (BMR), including absolute energy expenditure, energy expenditure per kilogram body weight, energy expenditure per kilogram FFM, energy expenditure per m^2 have previously been summarised [573]. In children these have also been expressed as a percentage of values obtained in healthy children of the same age or same surface area or same height. In infants with growth failure, both the BMR of the body and the tissue specific BMR may be reduced, while BMR kg^{-1} body weight may be increased due to preferential preservation of the brain, which has a high metabolic rate [573]. Similarly, TEE may be low when expressed in relation to values obtained in children of the same age, and normal when it is expressed in relation to healthy children of the same weight. The hypermetabolic effect of disease and the hypometabolic effect of weight loss alter BMR to a greater extent than in health, even when age, weight and height are taken into account, which affects the accuracy of expressing TEE as a ratio to BMR (i.e. PAL) [574]. PAL values based on measured BMR and predicted BMR (based on values established for healthy subjects), therefore, can vary widely, especially in acute disease, which typically increases BMR.

409. As with energy intake, energy expenditure does not necessarily indicate the requirements of the undernourished patient who is in need of repletion, or the requirements of the over-nourished patient, who is in need of depletion of excess fat.

410. Measurements of TEE have helped establish important concepts about energy requirements in disease. Some of the practical and theoretical principles of assessment of energy requirements in pathological states can be appreciated by considering the simultaneous changes in BMR, physical activity and TEE produced by acute and chronic diseases and the ways in which some of them are calculated.

Diseases in adults

411. Both TEE and the energy requirements of many diseases are decreased, mainly because of a reduction in PAEE. This reduction in PAEE can occur because disease produces lethargy and restricts physical activity (e.g. pain due to claudication – angina and arthritis are expected to do the same). It also occurs because treatment, especially in hospital, usually

requires restricted physical activity. Loss of weight will contribute to the reduction in TEE, partly because it reduces the energy expended in physical activity, and partly because it reduces BMR.

412. The effects of chronic diseases on energy expenditure are that TEE is normal or decreased [67]. In those with advanced disease or disease-related weight loss, both PAEE and TEE are usually decreased, despite a possible increase in BMR. The weight loss that may occur in such diseases is more likely to be due to a decrease in energy intake than an increase in energy expenditure. A possible exception to this general rule concerns subgroups of patients with anorexia nervosa, who have been reported to have increased PAEE and TEE, when adjusted for weight [575]. However, some studies of women with anorexia nervosa show no increase in TEE, after adjustment for weight [576]. When no adjustment for weight is made, TEE (MJ/day) is likely to be lower than in healthy women of the same age.

413. Acute diseases increase REE above that predicted for healthy individuals of the same age weight and height by up to 100% [577], although usually 0–40%. Both the magnitude and duration of the increase are dependent on the severity of disease. The effect of 'injury' on BMR is also influenced by age, e.g. the increase in BMR after surgery may last a few days after elective surgery in adults and only a few hours in infants [578]. Acute or sub-acute diseases usually cause a decrease in lean body mass. After the early phase of an illness, therefore, BMR may decline below pre-illness BMR before beginning to return to normal in the recovery phase.

414. In studies where the TEE of bed-bound artificially ventilated patients is measured, e.g. those with head injuries or other critical illness, BMR is frequently increased, but TEE is usually not elevated, mainly because of the associated reduction in physical activity [67]. The overall result is that TEE is normal or even decreased compared to values obtained in healthy subjects in free living circumstances, with the exception of the most severe acute diseases, such as burns, when TEE may be transiently elevated above normal[577].

415. In summary, in most of the chronic conditions examined, BMR adjusted for weight is usually normal or slightly increased (about 10%, e.g. HIV/AIDS), while in most acute conditions it is usually increased (0–50% and occasionally more). This increase in BMR is counteracted by the decrease in PAEE, with the overall result that TEE is usually normal or decreased. More severe acute disease produces greater increments in BMR and greater reductions in PAEE.

Diseases in children

416. Assessment of the energy requirements of children is more difficult than in adults because of the need to consider growth and appropriate ways of expressing energy expenditure.

417. In children, most chronic conditions do not produce an increase in TEE adjusted for body weight, despite a possible increase in BMR (e.g. cystic fibrosis [579]). There are some exceptions, such as subgroups of patients with cystic fibrosis (cystic fibrosis genotype, homozygous delta F508 [580]) and some children with congenital heart disease [581]. The general

situation is analogous to that observed in adults, as is that for acute conditions, where TEE is not increased (actually decreased) because of the reduction in PAEE.

Summary

418. The lack of accurate information on TEE in a large number of diseases, does not allow a comprehensive assessment of the field. In those conditions which have been investigated, TEE is usually normal or reduced, partly because of a reduction in body weight and FFM (disease-related malnutrition or neurological causes of wasting), and partly because of reduced physical activity. The reduced physical activity compensates for any increase in BMR, which is common in acute diseases. There are some exceptions, such as subgroups of patients with cystic fibrosis, anorexia nervosa, and congenital heart disease, where TEE has been reported to be increased. Such patients are often underweight, and therefore weight adjustments are necessary to demonstrate differences compared to control groups. Without such adjustments, TEE is again typically not increased.

419. In determining energy requirements in disease there is a need to consider not only the energy required to maintain energy balance, but also the energy required to change body composition at different rates in both under-nourished and over-nourished patients.

Appendix 7. Dietary determinants of energy intake and weight

Background

420. The aim of this Appendix is to consider the role of dietary factors in relation to risk of weight gain, and to determine whether specific factors can be identified that predispose to, or protect against, a positive energy imbalance, and hence weight gain.

421. While many individuals are weight stable, and therefore in energy balance, an increasing proportion are gaining weight and, therefore, have a chronic positive energy imbalance. The HSE 2009[370] shows that between 1993 and 2007, the proportion of normal weight adults decreased, the proportion overweight remained the same, while the proportion obese increased (see Tables 2 and 3). The proportion of morbidly obese adults doubled over the same time period.

422. Body weight is only gained when energy intake exceeds energy expenditure for a prolonged period. Studies of basic physiology under standardised conditions, and controlled intervention studies involving manipulations of the components of energy balance, clearly demonstrate weight loss with underfeeding and weight gain with overfeeding [582]. It is important to consider energy intake in the context of an individual's energy expenditure. Weight gain does not necessarily result from a high absolute energy intake, but from an intake which exceeds energy needs, even as a small fraction of energy flux. The coupling between energy intake and expenditure is, therefore, central to energy balance [109]. Energy flux, the absolute level of energy intake and expenditure under conditions of energy balance [30;583], will be considered further in Appendix 9.

Appetite control and energy balance

423. In most adults, adiposity and body weight are remarkably constant despite huge variations in daily food intake and energy expended [584]. A powerful and complex physiological system exists to balance energy intake and expenditure, composed of both afferent signals and efferent effectors. This system consists of multiple pathways which maintain the drive to eat. In the circulation, there are hormones which act acutely to initiate or terminate a meal, e.g. the gut peptides ghrelin and cholecystokinin, and hormones that reflect body adiposity and energy balance, e.g. insulin and the adipose tissue hormones leptin and adiponectin. These signals are integrated by peripheral nerves and brain centres, such as the hypothalamus and brain stem. The integrated signals regulate central neuropeptides, which modulate feeding and energy expenditure. This energy homeostasis, in most cases, leads to a stable body weight [585;586].

424. Often, a prolonged period of positive energy imbalance will lead to a noticeable increase in weight, or often waist circumference, which then leads to behavioural changes to lose the extra weight. This cognitive contribution to energy balance regulation is not well characterised.

425. The manipulation of energy intake has been shown to result in compensatory changes in energy expenditure. In obese and non-obese individuals, the response to a negative energy

imbalance is an adaptive suppression of thermogenesis, which occurs in the resting component of TEE (i.e. in BMR, thermic response to food or in sleeping metabolic rate) and/or in the non-resting components of energy expenditure (walking, bicycle exercise and spontaneous physical activity) [587-590]. There is considerable inter-individual variation in this response and, in most studies, this corresponds to mean values of 5–15% of TEE in either the resting or non-resting components [591].

426. Overfeeding produces much less compensatory change in energy expenditure than food restriction [592-594]. Overall, adaptive changes in energy expenditure are small and changes in body weight and composition are the primary mechanisms by which the body accommodates energy excess or inadequacy [582;592]. Weight gain includes an increase in some metabolically active lean tissue, which will increase energy expenditure, and the extent of this will vary according to the composition of the weight gain [595]. Nevertheless, overall alterations in energy balance must be accommodated by adjustments in the net retention of the major energy-yielding macronutrients: carbohydrate, protein, and fat.

427. The body's regulatory systems, therefore, are developed to avoid depletion of body energy stores, whereas the systems that prevent excessive accumulation of fat in response to excess energy intake may be over-ridden by other factors, e.g. hedonistic features of food [409]. Psychological, social, and cultural factors are important underlying influences on dietary patterns and PAEE.

428. While brain mechanisms control appetite, a number of sensory and environmental factors contribute to overstimulation of the sensory systems, producing sensory reward signals that are stronger than can always be controlled easily by satiety signals [596]. Factors that contribute to over stimulating the brain's food reward systems relative to satiety signals include food palatability and appearance, sensory-specific satiety, food variety, food availability and the effects of visual stimulation and advertising [597].

Substrate utilisation and energy balance

429. Dietary carbohydrate, protein and fat must first be broken down into smaller molecules, i.e. monosaccharides, amino acids and free fatty acids respectively, before the energy present can be utilized by the tissues. The digestive processes break down the larger molecules into smaller ones, which are then transported in the blood to be either used directly or stored mainly as glycogen (glucose), protein (amino acids) and triglycerides (free fatty acids) [598].

430. The types of fuels utilized by tissues varies considerably (e.g. glucose, free fatty acids, ketone bodies, amino acids, butyrate) and partly depends on the availability of circulating fuels, but some tissues also have specific fuel requirements or preferences, e.g. glucose is essential for cells that are obligatory anaerobes, such as red blood cells. The vast majority of the energy expenditure of the brain is derived from glucose, but during total starvation, when glycogen stores are depleted, ketone bodies (produced from free fatty acids and some amino acids in the liver) become the dominant energy source. This adaptive response to starvation, which reduces demand for glucose and hence spares use of gluconeogenic amino acids and protects lean body mass, appears to occur to a lesser extent in lean subjects [599]. Glutamine is considered an important fuel for the small intestine and short chain fatty acids, produced by the colonic fermentation of carbohydrate, are thought to provide a substantial amount of energy for the large intestine [598].

431. Integrated fuel homeostasis relies on interactions among numerous tissues to orchestrate the transition between widely varying states, including the fed state, fasting, and exercise. The ability of tissues to adapt to changes in metabolic status and fuel availability depends on signals conveyed by hormones, cytokines, and fuel substrates, which are sensed through a variety of cellular mechanisms. There is an inter-tissue flux of fuel substrates in both the fed and fasted states. The major hormones known to be involved in the coordination of this are insulin, glucagon, catecholamines, growth hormone and corticosteroids [600].

432. The distribution of food energy between the macronutrients differs between cultures and countries, reflecting a wide range of carbohydrate-protein-fat ratios at which energy balance can be maintained [601]. When people are in energy balance the substrate oxidation pattern shifts to closely reflect the diet macronutrient composition. In healthy populations, subjects have been shown to switch their fuel use based upon substrate availability, e.g. increase fat oxidation in response to a high fat diet [602-608]. It takes several days for substrate utilisation to adapt to a change in diet macronutrient composition [602;603;605;608] and modification of glycogen stores has been implicated in this adaptation [609]. Adjustment in fat oxidation to a high fat diet has been shown to be accelerated by an increased level of exercise [610;611]. Adaptation to an increased proportion of dietary fat has been shown to lead to measurable changes in the capacity to store, mobilise, transport and oxidise fat [612]. There is also a delay of several weeks in the change in protein oxidation following a change in the habitual level of protein intake and this results in marked changes in nitrogen balance until protein oxidation has adapted to the new level of intake [613].

433. In the obese insulin-resistant state there appears to be an impaired capacity to regulate fat oxidation (metabolic inflexibility) [614]. Several studies suggest that obese, and formerly obese, subjects adapt fat oxidation to fat intake more slowly than lean subjects [605;615-619] and dietary fat oxidation has been observed to be inversely associated with percentage body fat [620].

Methodological constraints

434. Prospective studies that have evaluated dietary intake in conjunction with weight or body mass index (BMI) change have largely yielded weak and inconsistent results. In part, this may be a true reflection of the multi-factorial nature of weight gain and obesity, but it could also relate to methodological difficulties inherent in these studies, e.g. the need to measure the small energy imbalances relative to total energy flux that have been estimated to account for population weight changes [621;622].

435. Body weight and composition are the integrated product of previous dietary and physical activity habits, and so nutrients, foods or broader dietary habits measured on a small number of occasions may not be related to the longer-term development of weight change. Many dietary factors are highly correlated and physical activity or other lifestyle factors are also important covariates [623].

436. In observational studies, a major difficulty is the accurate assessment of dietary exposures, which may vary over time. The most commonly used method in prospective cohort studies is the food frequency questionnaire (FFQ). These are designed to assess usual eating habits, over recent months or years, and comprise a list of foods most informative about the nutrients or food of interest

437. The degree of error associated with the FFQ is considered larger than that associated with seven- day diaries of all food and drink consumed, which may affect the ability of a study to detect associations between diet and health outcomes [624], e.g. an association between dietary saturated fatty acid intake and breast cancer risk, observed using seven-day food diaries, was not observed when FFQ were used [625]. The validity of using FFQ, however, is increased in larger studies where measurement error is more likely to be overcome by large dietary heterogeneity [626].

438. In dietary surveys, energy intake tends to be under-reported, relative to estimated energy needs, by an average of 20-25% [627;628]. The under-reporting of energy intake is more pronounced among overweight and obese, than among lean, adults and children [511;629-633]. The nutritional composition of the unreported energy intake is unknown, and statistical adjustments, which attempt to correct for energy intake, tend to be made based on energy alone. The NDNS series employed a seven-day weighed intake dietary record to assess dietary exposures, where respondents were asked to keep a weighed record of all food and drink consumed, both in and out of the home, over seven consecutive days [8], but under-reporting was still prevalent (see Table 30 below).

439. There is a paucity of controlled dietary intervention studies to test aetiological hypotheses. Because of the nature of such interventions it is rarely possible to design a double-blind trial and the process of informed consent and baseline screening may act as an intervention in itself by raising awareness of the diet or health issue and prompting behaviour change. Dietary change may be difficult to sustain as traditional dietary practices can be well established and strongly habituated. Numbers of dropouts from trials are frequently high and the extent of compliance is often difficult to measure. In terms of prevention, the mean weight change is small (especially superimposed on the background population weight increase) and there is large inter-individual variability, which has implications for sample size and power. Accordingly, there are few large-scale, long-term, well-controlled dietary intervention studies [623].

440. Overall, these methodological constraints are likely to predispose studies towards negative findings and attenuate any observed associations. This is reflected in the relatively few observational studies and dietary surveys that have demonstrated the basic physiological principles dictating habitual energy intake must exceed expenditure for weight gain to occur [634].

The National Diet and Nutrition Survey reported energy intakes

441. Surveys in the UK, both of dietary and household purchase data, indicate energy intakes by the population below the prevailing EAR. The NDNS series [2-11] consistently show average energy intakes below the EAR in all population groups (see Tables 31 and 32). The NDNS and other surveys, however, also show that the number of people classified as overweight or obese is increasing (see Table 3).

Children and adolescents aged 4-18 years

442. Mean energy intakes were below the EARs at 80-90% of the EAR (see Table 30). In girls aged 15-18 years mean energy intake was 77% of the EAR.

Adults aged 19-64 years

443. Mean energy intakes for adults were 82-94% of EAR values for men and women in all age groups (see Table 30). Data from the two surveys of adults in 1986/87 and 2000/01 showed that the prevalence of obesity or overweight had increased from 45% of men and 36% of women who were obese or overweight in 1986/87 to 66% of men and 53% of women in 2000/01. This trend is confirmed by data from the Health Surveys (see Table 3). Mean energy intakes in the 1986/87 survey were also below EAR values. Comparing the 1986/87 and 2000/01 surveys, mean energy intake had fallen slightly in men but was unchanged in women.

Adults aged 65 years and over

444. Mean energy intakes were below EAR values. In the free-living group mean energy intake was 85% of EAR in men and 76% in women and for men was lowest in the 85+ age group. In the institution group mean intake was over 90% of the EAR.

445. In Table 30, energy intake is presented as a percentage of the EAR for all NDNS age/sex groups. Standard EAR values were used for each age/sex group as published in the Dietary Reference Values report [1]. EAR values for each age/sex group were derived from BMR calculated from the modified Schofield equations using mean body weight values for each age/sex group. PAL values for adults were taken as 1.4.

Table 30. Mean daily reported energy intake (MJ) as a percentage of EAR using standard EAR values

Gender and age of respondent	Mean energy intake (MJ)*	Mean intake as % of EAR**	Number of subjects
Males and females 1.5-2.5 years***	4.39	90%	576
Males and females 2.5-3.5 years***	4.88	84%	606
Male aged (years)			
3.5-4.5***	5.36	82%	250
4 – 6	6.39	89%	184
7 – 10	7.47	91%	256
11 – 14	8.28	89%	237
15 –18	9.60	83%	179
19-24	9.44	89%	108
25-34	9.82	93%	219
35-49	9.93	94%	253
50-64	9.55	92%	253
65+ Free-living	8.02	85%	540
65+ Living in an institution	8.14	91%	93
Female aged (years)			
3.5-4.5***	4.98	82%	243
4 – 6	5.87	91%	171
7 – 10	6.72	92%	226
11 – 14	7.03	89%	238
15 –18	6.82	77%	210
19-24	7.00	86%	104
25-34	6.61	82%	210
35-49	6.96	86%	318
50-64	6.91	87%	259
65+ Free-living	5.98	76%	735
65+ Living in an institution	6.94	90%	319

*Reported energy intakes as listed in NDNS[2-11]

**Energy intake as a percentage of EAR was calculated for each respondent using the EAR appropriate for sex and age.

*** Energy intakes per kilogram body weight was used to calculate intake as % of EAR on a group basis for 1½-4½ year age group

446. Table 31 presents energy intake as a percentage of EAR for the 19-64 age group only (NDNS adults 2000/01). The EAR was calculated for each subject using individual body weight data to estimate BMR, and PAL values derived from the seven-day physical activity records. The mean PAL values reported using seven-day physical activity questionnaires were 1.70 for women and 1.85 for men (see Table 31).

Table 31. Mean daily reported energy intake (MJ) as a percentage of the EAR using EAR values based on individual BMR and reported PAL value

Gender and age of respondent	Mean energy intake (MJ)*	Intake as % EAR**	Number of subjects
Male aged (years)			
19-24	9.60	66%	54
25-34	9.92	68%	144
35-49	9.99	72%	283
50-64	9.57	73%	216
All 19-64	9.82	71%	697
Female aged (years)			
19-24	7.13	69%	66
25-34	6.61	67%	187
35-49	7.05	71%	341
50-64	7.07	73%	260
All 19-64	6.97	71%	854

*Reported energy intakes as listed in NDNS[5]

** EAR derived for each individual using BMR estimated from modified Schofield equations and actual body weight measured during the survey period. PAL calculated for each individual using physical activity records.

447. The apparent contradiction between increasing levels of obesity and low levels of energy intake reflects the extent of under-reporting in the NDNS, and other, surveys. In the NDNS of adults 2000/1, the median energy intake expressed as a multiple of calculated BMR was 1.11 with a value of less than 1 for 50% of subjects. In the NDNS elderly survey, median energy intake expressed in this way was 1.22 x BMR with a value of less than 1 for 24%. Clearly, since none of the subjects were observed to be losing weight, such intakes were physiologically implausible and must have reflected under-reporting and other methodological errors. This largely accounts, therefore, for the difference between recorded intakes and assumed energy requirements (see Table 30).

448. The EAR for adults was calculated using a PAL value of 1.4, on the assumption that this was representative of the inactive lifestyle of much of the population [1]; however, DLW measurements of energy expenditure in specific population groups suggests a higher PAL value may be more accurate, e.g. a PAL value of 1.7. Assuming this is the case then the mismatch between recorded energy intakes and actual energy requirements is even greater, e.g. a mean PAL value of 1.7 was observed in women from physical activity questionnaire records, which when used to calculate individual EAR values suggested under-reporting of energy intakes was as high as 30% (see Table 31).

Temporal trends in reported energy intakes and diet macronutrient composition in the UK

449. Comparisons between the 1986/7 and 2000/1 NDNS for adults data show that, overall, men and women in the 2000/1 survey reported a significantly higher proportion of their energy intake from protein and carbohydrate and a significantly lower proportion from fat than in 1986/7; men, but not women, also had significantly lower energy intakes in 2000/1

than 1986/7 [5;6]. In the EPIC Norfolk cohort (n= 30,452; assessed 1993-1997), dietary assessment with both FFQ, and 7-day food diary in a sample of 2,117, yielded similar intakes of macronutrients when expressed as a percentage of total energy intakes, which were in accord with values obtained from the NDNS 2000/1, e.g. total fat intake was 33% total energy [626]. There was no significant difference in the proportion of energy intake from alcohol between the two NDNS surveys (see Table 32).

Table 32. Comparison of mean daily energy and macronutrient intakes between the NDNS for adults 1986/7 and 2000/1[5;6]

	1986/7	2000/1
Men		
Total energy intake (MJ)	10.30	9.72
% energy from carbohydrate	41.6	44.7
% energy from protein	14.1	15.4
% energy from fat	37.6	33.5
% energy from alcohol	6.9	6.5
Women		
Total energy intake (MJ)	7.05	6.87
% energy from carbohydrate	43.0	46.7
% energy from protein	15.2	15.9
% energy from fat	39.2	33.5
% energy from alcohol	2.8	3.9

Dietary assessment in both the adult surveys used a seven-day weighed intake dietary record.

450. Eating out in the NDNS is defined as all food and drinks consumed out of the home, regardless of where they were prepared. The definition includes packed lunches brought from home to eat at work or elsewhere. Table 33 shows that the proportion of dietary energy, all macronutrients, and alcohol has increased by 2-4% in 2000/1 compared with 1986/7, except for alcohol consumption by women, which increased by 9%.

Table 33. Percentage contribution of eating out to energy and macronutrient intakes for adults in 1986/87 and 2000/01[5;6]

	Percentage of intake from eating out			
	1986/7		2000/1	
	Men	Women	Men	Women
Total energy	34%	24%	36%	26%
Total fat	32%	25%	36%	28%
Saturated fat	32%	25%	36%	27%
Total carbohydrate	32%	23%	34%	25%
Protein	28%	21%	32%	24%
Alcohol	55%	36%	58%	45%

451. Until 2000, the National Food Survey (NFS) provided a continuous sample survey in which about 6,000 households per year in Great Britain kept a record of the type, quantity and costs of foods entering the home during a one week period [635]. From 1996, the survey also included about 700 households in Northern Ireland. Nutritional intakes were estimated from the survey data. An analysis of temporal trends in food composition data from 1974 to

2000 shows that the percentage food energy from total fat declined, and that from carbohydrate increased, between the mid 1980s and 2000 (see Figure 6); the proportion of food energy as saturated fatty acids declined throughout the duration of the survey. This analysis did not include soft and alcoholic drinks and confectionery and food not taken home, as this data was unavailable for the whole time period. The estimated daily energy intake decreased from 1974 to 2000, from 9.5 MJ (2260 kcal) to 7.3 MJ (1750 kcal) (see Figure 7), while average protein intakes were relatively constant throughout, e.g. 68.9 g/day in 1974 and 66.3 g/day in 2000, but would have increased as a proportion of food energy. A downward trend in average daily energy intake has been observed in the NFS since 1964 [636].

Figure 6. Estimated mean daily intakes of fat and carbohydrate between 1974 and 2000 in the NFS, as a percentage of household food energy[635]

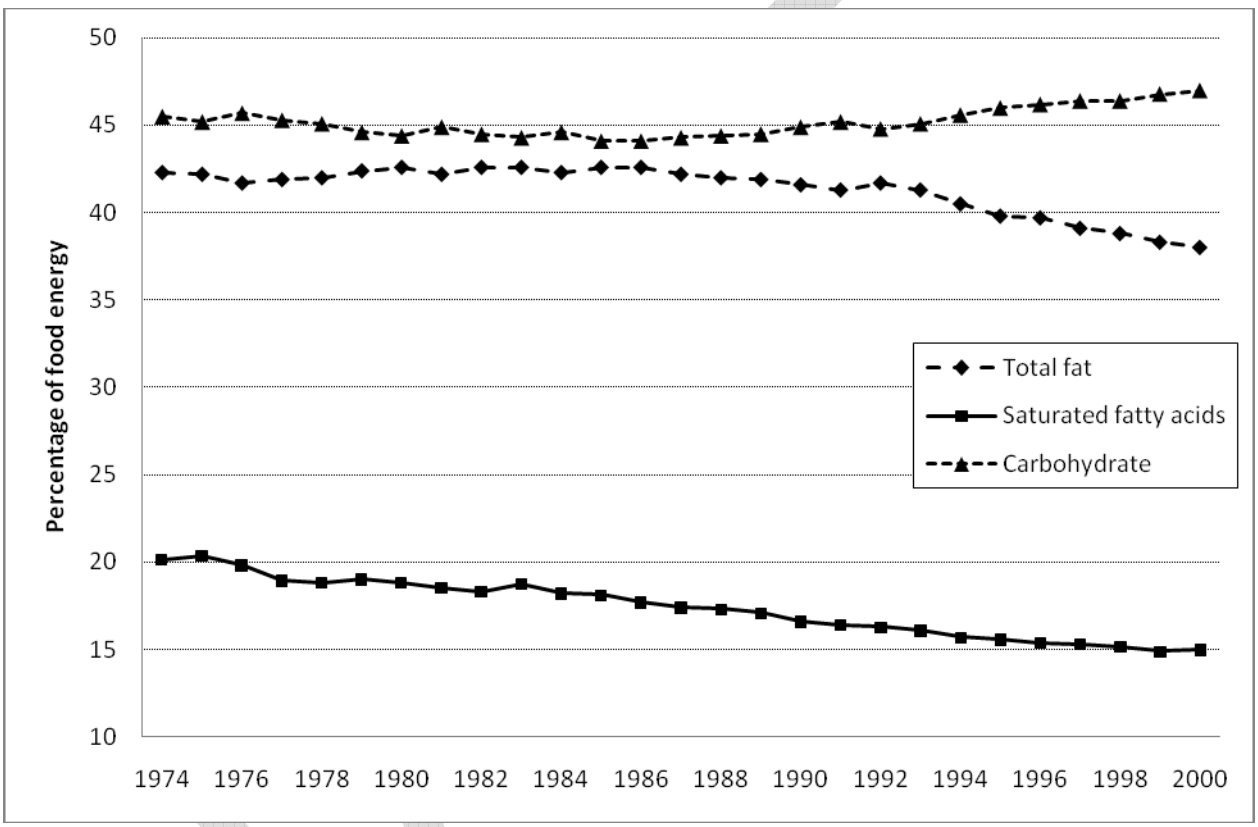
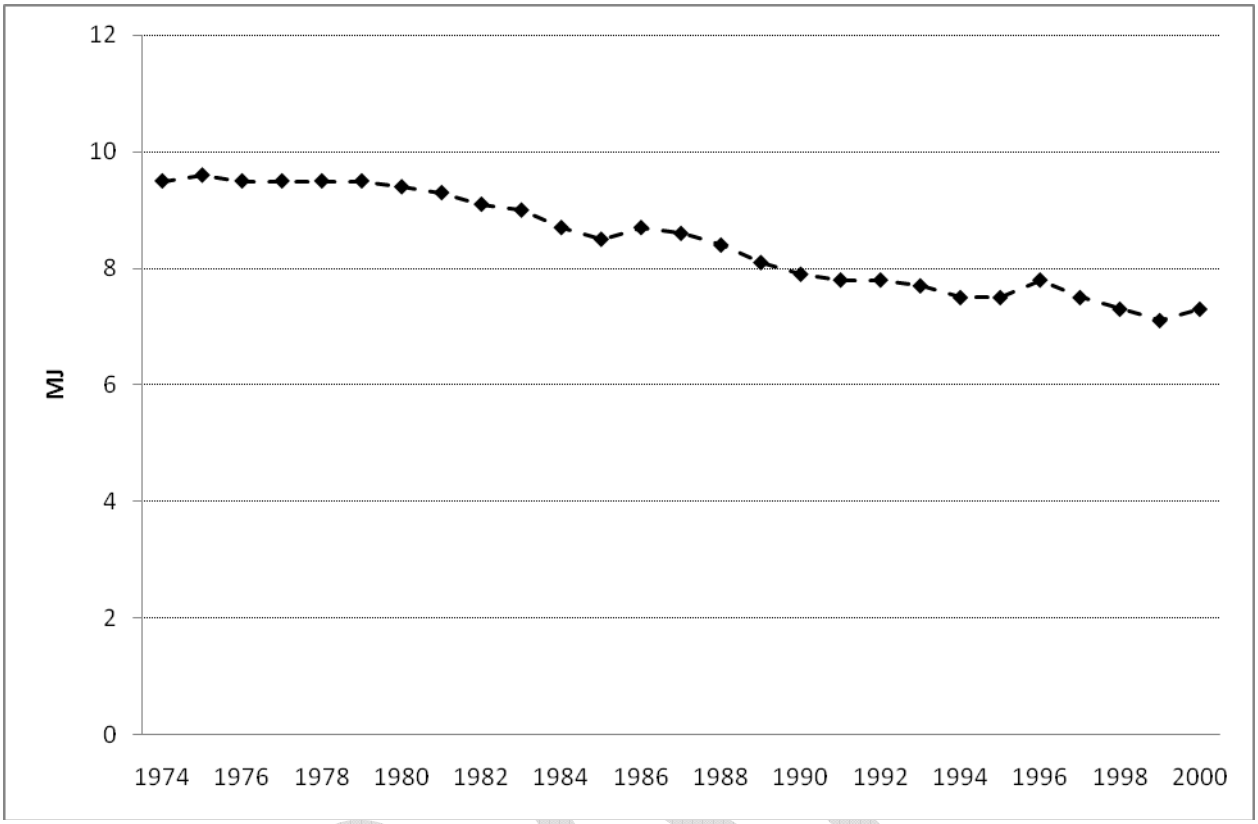


Figure 7. Estimated mean energy intakes (MJ), excluding soft and alcoholic drinks and confectionery and food not taken home, between 1974 and 2000 in the NFS[635]



452. The UK Expenditure and Food Survey (EFS) superseded the NFS and the Family Expenditure Surveys in 2001. Under-reporting in the EFS is thought to be lower than in the NFS as it does not focus on diet, but on household expenditure across the board and is largely based on till receipts. A change in the EFS methodology, however, makes the estimate of the year on year change unreliable between 2000 and 2001-02. The Family Food 2006 report presents trends in purchases by type of food and converts these into energy and nutrient intakes based on a database of nutrient values provided by the Food Standards Agency [636]. The Family Food 2006 report shows very little change in the estimated macronutrient intakes, as a percentage of food energy, since the 2000 NFS (see Table 34) and average daily energy intake estimates (excluding food eaten out, but including alcoholic drinks) were 8.8 MJ (2098 kcal) in 2001/2 and 8.7 MJ (2074 kcal) in 2006. The estimated total average daily energy intake, including food eaten out, was 9.8 MJ (2351 kcal) in 2006.

Table 34. Estimated UK mean daily energy and nutrient intake from all food and drink from 2003 to 2006 as a percentage of food energy[635].

	NFS 2000	2003-4	2004-5	2005-6	2006	% change since 2003-04
Fat	38.0	38.3	38.2	38.1	38.5	+0.5
Fatty acids:						
Saturates	15.0	14.8	14.7	14.6	14.7	-0.4
Monounsaturates	-	14.1	14.1	14.0	14.2	+0.5
Polyunsaturates	-	6.8	6.8	6.8	7.0	+2.5
Carbohydrate	47.0	47.6	47.6	47.6	47.2	-0.7
Non-milk extrinsic sugars	-	15.0	14.8	14.4	14.2	-5.5
Protein	-	14.1	14.3	14.3	14.3	+0.9

453. The NFS assessed food eaten outside the home in Great Britain from 1994 [637], but the data are less reliable than estimates obtained from the EFS [636]. The EFS estimate of average daily energy intakes from food and drink eaten outside the home shows a small decrease since 2001-02 (see Table 35).

Table 35. Eating out mean daily energy intakes estimated in NFS[637] and EFS[636]

	NFS 1995	NFS 2000	EFS 2001-02	EFS 2002-03	EFS 2003-04	EFS 2004-05	EFS 2005-06	EFS 2006
Total energy *								
MJ	1.0	1.0	1.3	1.3	1.3	1.2	1.2	1.2
kcal	240	230	310	309	303	288	280	276

* includes alcoholic drinks, soft drinks and confectionery.

454. Overall, surveys suggest that diet macronutrient composition has changed over the past 20 years or more, with an increased proportion of energy from carbohydrate and a decreased proportion from total fat and saturated fatty acids. There also appears to have been a decrease in average daily energy intakes, which appears to date from the 1960s.

455. The under-reporting of energy intakes, estimated to be about 30% in the NDNS for adults aged 19-64 years when individual anthropometric and physical activity questionnaire data were used to determine BMR and PAL (see Table 7), means that the macronutrient composition of almost a third of the energy intake was unknown. Furthermore, under-reporting is more pronounced among overweight and obese, than among lean adults and children [511;629-633]. The increasing prevalence of overweight and obesity (see Table 3), therefore, further complicates the issue of determining temporal trends in diet composition. Household expenditure surveys, however, do support the observed change in macronutrient composition and energy intakes observed in the NDNS.

456. Household expenditure surveys and the NDNS suggest that there has been a reduction in energy intakes over the same time period in which there has been an increase in the prevalence of those overweight and obese. The issue of under-reporting of energy intakes, however, makes interpretation of this difficult.

Diet composition and weight gain

457. The role of diet composition in the development of weight gain and obesity is controversial [638;639]. Several areas have been the focus of research including energy density, macronutrient composition and dietary patterns.

Energy density

458. Energy density describes the amount of energy per unit weight of food or diet. The energy density of individual macronutrients reflects their metabolisable energy content, such that fats and oils are the most energy-dense, followed by ethanol, then protein and carbohydrate, which are least energy-dense (see Table 1 for metabolizable energy content of macronutrients). Non-starch polysaccharides that are fermented in the colon are less energy dense still.

459. The energy density of foods and diets varies depending on the water content and concentration of the different macronutrients, and of non-starch polysaccharides [640]. In general, low energy-dense foods and diets are high in non-starch polysaccharides, and also in water. Cereals and vegetables cooked in water, and most fruits, are examples of low energy-dense foods. Low energy-dense foods are often high in vitamins and minerals and other bioactive constituents [641]. Many processed or convenience foods have a relatively high energy density and are usually high in fats or oils, and/or processed starches and added sugars [642]. Processed, high energy-dense foods are often low in micronutrients and non-starch polysaccharides.

460. Gastric distension plays a role in regulating the size of a meal. An isoenergetic meal containing foods with a low energy density causes more gastric distension than does a meal

containing foods with a high energy density [643]. In short-term intervention studies, conducted over several days, diets that are relatively high in energy density have generally been shown to result in greater energy intakes compared with diets that are lower in energy density in both men and women [644-648]. These studies have also shown that individuals tend to eat a fairly consistent weight or volume of food over the course of several days, regardless of the energy density of their meals. Several short-term studies have further shown that energy density, independently of macronutrient composition, affects energy intake [644;646;649-651], i.e. energy density, independently of fat content, directly influenced energy intake.

461. These studies suggest that high energy-dense diets may undermine normal appetite regulation, a process that has been termed 'passive overconsumption'. An inability to recognise the energy density of food and compensate appropriately to maintain energy balance could lead to unhealthy weight gain, and overweight and obesity. Dietary fat is a major determinant of the energy density of foods, but some reduced-fat, and, therefore, higher carbohydrate, foods are highly energy dense [652]. High carbohydrate foods do not necessarily have a low energy density and although it may be easier to overeat on high fat than low fat foods, it appears that it is not simply a case of replacing fat with carbohydrate in the diet as a means to reduce energy density [653].

462. Although some cross-sectional epidemiological studies have linked dietary energy density with higher BMI values, the data are inconsistent [654], and, at this time, there are only a few longitudinal cohort studies that have specifically investigated a link between dietary energy density and obesity risk.

463. A prospective study in children assessed the energy density of the diet at 5 and 7 years in relation to weight gain at 9 years of age [655]. A higher dietary energy density at age 7 years, but not age 5 years, was observed to be modestly associated with increased excess fat mass at age 9 years. A subsequent analysis identified a dietary pattern which explained dietary energy density, fibre content, and percentage of energy intake from fat, that was related to fatness in children [656] (see dietary patterns section below).

464. Another study in children found overall dietary energy density not to be associated with change in percentage body fat, body mass index, or waist circumference, but when energy density was calculated excluding beverages, participants who had the most energy-dense diet in childhood had the highest gain in weight into adolescence [657]. This suggests that the method chosen to determine dietary energy density may affect the study conclusions.

465. Another study in children and adolescents investigated the relation between energy-dense snack food consumption and subsequent weight gain [658]. The consumption of energy-dense snack foods was not observed to be associated with increased fat mass [658]. A positive relationship between hours of television viewed per day and energy-dense snack food consumption was, however, observed.

466. Three prospective studies haves been conducted in adults [659-661]. In one [659] dietary energy density was not associated with subsequent change in body weight overall, but in women, energy density was positively associated with weight gain among the obese and inversely associated with weight gain in normal-weight women. In men, however, there was a non-significant inverse trend between dietary energy density and weight gain in the obese. The two other studies in women observed higher dietary energy density to be associated with greater weight gain [660;661]. In one further study, increased dietary energy density was

associated with gestational weight gain [662].

467. Frequent nut consumption, a high-fat, energy-dense food, has been shown not to lead to weight gain in well-controlled nut-feeding trials, and prospective studies suggest frequent nut consumption is associated with reduced risk of weight gain [663-665]. Residual confounding, however, with other dietary and lifestyle differences may be a factor affecting interpretation of observational studies. Nuts are also relatively rich sources of protein, micronutrients and non-starch polysaccharide and effects on satiety and faecal fat loss may be factors influencing the observed lack of weight gain [663;666-668]. When considering relatively high energy-dense foods in relation to weight gain it may be more relevant, therefore, to focus on foods that are also poor sources of micronutrients and non-starch polysaccharide, such as many processed and convenience foods.

468. Several prospective studies, while not directly examining the role of dietary energy density in weight regulation, have linked weight gain with consumption of convenience foods, which typically have an energy density very much greater than household foods [669-671]. In children aged 9-14 years (7,745 girls and 6,610 boys), increased reported consumption of fried foods away from home over one year was associated with increased BMI [670]. In adults aged 18-30 years (n=3,031), the reported frequency of fast-food restaurant visits at baseline was positively associated with 15 year changes in body weight [669]. Consumption of hamburgers, pizza, and sausages (as a proxy for convenience-food consumption) was independently associated with weight gain in a cohort of 7,194 adults with a mean age of 41 years who were followed-up for a median of 28.5 months [671].

Macronutrient composition

469. The relative impact of the different macronutrients on energy balance and risk of weight gain has been the focus of much research, with particular emphasis on the proportion of energy from fat in promoting weight gain. In the UK, however, survey data suggests there has been a decline in the percentage of energy intake from fat during the last 2 decades, which has corresponded with an increase in the prevalence of overweight and obesity. Evidence from observational studies of a specific role for the proportion of energy from dietary fat are inconsistent [638;639]. A meta-analysis of *ad libitum* low-fat high-carbohydrate dietary intervention studies (16 trials; 2-12 months duration; mean fat reduction of 10.2% total energy) observed that a reduction in dietary fat caused spontaneous weight loss (mean weight loss of 3.2 kg as compared to control groups) [672].

470. In a subsequent review, however, it was noted that in randomised trials lasting for a year or more, fat consumption within the range of 18% to 40% of energy appeared to have little effect on body fatness. The weighted mean difference was a weight reduction of 0.25 kg overall (i.e. less weight loss on the low-fat diets) and a weight increase of 1.8 kg for trials where the control group had received a similar intensity of dietary instruction and counselling to the intervention group, but directed at the reduction of carbohydrate or total energy [673].

471. A major concern in any long-term study of dietary change is that compliance may deteriorate with time, which makes it difficult to assess the magnitude of effect of any intervention [674]. In general, studies of fat reduction have been hindered by a lack of a well-documented measure of compliance [673]. Based on a meta-analysis of trials investigating changes in carbohydrate and fatty acid intake on serum lipid and lipoprotein levels [675] it was

suggested that the reported changes in serum lipid and lipoprotein concentrations in the randomised trials lasting a year or more did not support the notion that failure to observe a substantial weight loss on long-term low-fat diets was simply the result of noncompliance [673].

472. The Women's Health Initiative randomised intervention trial of 48,835 postmenopausal women in the United States [676], found a reduction in energy from fat (mean fat reduction of 9% total energy) and an increase in energy from carbohydrate resulted in no weight change over 7.5 years in the intervention group, relative to the control group (weight difference of -1.9 kg, after 1 year and -0.4 kg after 7.5 years relative to control group). Intake of fibre, fruits and vegetables, total grains, and whole grains were also increased from baseline in the intervention group while remaining stable in the control group.

473. Overall, therefore, any long-term effects on body weight of dietary fat reduction are likely to be small and there is no strong evidence that lowering the proportion of energy as dietary fat would prevent weight gain [677].

474. Indeed, in a small but probably reliable study of Australian female nutrition students studied repeatedly over a 15 year period (1988-2003), increasing prevalence of overweight (from 15% to 34%), which related to increased energy intake with unchanged physical activity (PAL=1.64), occurred with a reduced proportion of dietary energy from fat and increased amounts from carbohydrate and protein. [678].

475. The proportion of carbohydrate in the diet tends to vary reciprocally with fat and it is difficult to segregate the impact of the total amount of carbohydrate in the diet from the total amount of fat [674]. While some prospective studies show an inverse association between the proportion of food energy as carbohydrate and weight gain, many others show no association, particularly in children [679-683].

476. As well as the total amount of fat or carbohydrate in the diet, studies have examined the role of fat and carbohydrate composition on weight gain. The evidence relating sugar intake *per se* to weight change is inconsistent [684]. Two carefully conducted 6 month trials of low-fat high-carbohydrate *ad libitum* diets, which compared complex with simple carbohydrates on weight gain, have observed no significant effect of carbohydrate composition [685;686]. By contrast, there is accumulating evidence to suggest that simple sugars in drinks do not possess the same satiating powers as sugars in solid food (the fluid medium rather than energy form or nutrient composition is thought responsible [687]) and that a high consumption of sugar-sweetened beverages may be a risk factor for weight gain and obesity [688;689]. Surveillance studies show a temporal association between *per capita* intake of sugar-sweetened beverages and increasing obesity rates [690]. A meta-analysis of studies (10 prospective; 5 experimental) investigating the role of sugar-sweetened beverage consumption in weight gain concluded that in well-powered prospective cohort studies with long periods of follow-up (6 studies), a positive association between greater intakes of sugar-sweetened beverages and weight gain and obesity in both children and adults was observed; the other cohort studies (4 studies) observed no significant association [691]. One subsequent study in children observed no association [692], while another observed that in girls but not boys, increased fruit juice intake rather than soft drink consumption was associated with weight gain [693]. A subsequent study in adults observed increased soft drink consumption to be associated with weight gain, obesity and developing metabolic syndrome [694]. Another meta-analysis (10 prospective studies; 2 randomised controlled trials) found no evidence to suggest sugar-sweetened beverages consumption affects weight gain in childhood and

adolescence[695].

477. Several prospective studies have observed an inverse association between wholegrain and fibre/non-starch polysaccharide intake and weight gain [434;681;696-699]; although the definitions used for dietary fibre/non-starch polysaccharide and wholegrain vary between studies. Conversely, intake of refined-grain foods was positively related to weight gain in one study [697], but not another [696].

478. A diet rich in wholegrain and non-starch polysaccharide may have beneficial effects on weight control through promoting satiety [700] and decreasing the digestibility of the energy-containing nutrients [701;702]. A review of 11 intervention studies (duration more than 4 weeks) of *ad libitum* non-starch polysaccharide intake and weight change found that consumption of an additional 14 g/day non-starch polysaccharide for more than 2 days was associated with a 10% decrease in energy intake and body weight loss of 1.9 kg over 3.8 months [703].

479. The glycaemic index was developed in the early 1980s [704] and is a measure of the glycaemic effect of a particular food compared with an equivalent amount of carbohydrate in the form of pure glucose or white bread. The glycaemic load of a serving of a specific food is the product of its glycaemic index and the grams of carbohydrate from a single serving of that food and combines quantitative and qualitative indicators of carbohydrate intake. Single meal studies have suggested glycaemic index may affect later *ad libitum* energy intake [705;706]. Short term studies, conducted over several days, investigating the effects of meals with contrasting glycaemic carbohydrate content have failed to demonstrate any differential effect on fuel partitioning of modulating the dietary glycaemic index or load [707;708]. The postprandial insulin response may be an important satiety signal [709], but glycaemic index-induced serum insulin differences appear insufficient to modify fuel oxidation and energy intake.

480. Results from prospective studies that have investigated whether a diet with a high glycaemic index or glycaemic load contributes to the risk of weight gain have been inconsistent [682;710-712]. Intervention studies investigating this have also produced inconsistent results [712;713;713-717].

481. Different types of fatty acids have different metabolic effects and it is possible that this extends to differences in risk of weight gain [718], e.g. animal work suggests that saturated fatty acids may be preferentially stored and high *trans* fatty acid intake may enhance the intra-abdominal deposition of fat [719]. Several prospective studies have observed *trans* fatty acid intake to be positively associated with weight gain [434;720] and postpartum weight retention [721]. In one study, the percent of energy from fat had only a weak positive association with weight gain, while percentage of energy from animal, saturated, and *trans* fatty acids had stronger associations [720]. Single-meal studies do not support a differential effect on satiety of different fatty acids [722;723].

482. Evidence from prospective studies relating the proportion of protein in the diet with weight change is inconsistent [681;683;724]. One intervention study that increased dietary protein intake from 12% to 25% of energy at a constant low-fat intake produced a greater magnitude of spontaneous weight loss than from a low-fat diet alone, after 6 months [725]. These differences persisted, but were attenuated after consumption of the study diets for 12 months [726]; the evidence suggested that the high protein diet reduced visceral fat more than expected from fat loss. In general terms populations consuming the highest levels of protein have the

highest levels of obesity even though in the short term high protein diets induce satiety and weight loss [727]. One explanation is that the satiating influence of dietary protein is adaptive [728], so that any acute influence on energy intakes as observed with high protein weight reducing regimes, will become less effective with time.

483. Short term studies, conducted over several days, have consistently shown that alcohol has an acute stimulatory effect on appetite [729]; however, results from prospective studies investigating alcohol consumption in relation to weight gain have been inconsistent [434;444;730-732]. This is a complex area to study given the specific under-reporting of alcohol intake, confounding by other variables and ethical differences in conducting intervention studies [623].

Micronutrients

484. Several large epidemiological studies have shown an inverse relationship between calcium intake and body weight or BMI [733]; however, a meta-analysis of 13 trials of calcium supplementation or increased provision of dairy products, conducted for 12 or more weeks observed no statistically significant association with a reduction in body weight [733].

Dietary patterns

485. The investigation of dietary patterns and eating behaviour, rather than specific nutrients, has become a focus of research. As discussed above, when considering relatively high energy-dense foods in relation to weight gain it may be more relevant to focus on foods that are also poor sources of micronutrients and non-starch polysaccharide. A dietary pattern that explained dietary energy density, fibre content, and percentage of energy intake from fat was identified in a dietary analysis of 521 children [656]. Higher pattern scores at 7 years of age, but less so at 5 years of age, were prospectively associated with greater fat mass and higher odds of excess adiposity at 9 years of age.

486. Increased fruit and vegetable consumption has been associated with reduced weight gain in several prospective studies [423;699;734]. The Mediterranean or 'prudent' diet pattern characterised by high intakes of vegetables, fruits, legumes, nuts and olive oil, together with a reduced intake of meat and meat products and full-fat dairy products has been associated with reduced weight gain in most studies [735-738], but not in all [739].

487. Most short-term studies, conducted over several days, [740-743], but not all [744], suggest habituation to large portion sizes may increase energy intake, but longer term interventions or prospective studies are lacking.

488. Three prospective studies have reported consumption of breakfast by adolescents and adults to be modestly associated with reduced weight gain, as compared with skipping breakfast [745-747], while another study found no consistent association [748]. In the EPIC-Norfolk cohort, an increased percentage of daily energy consumed at breakfast was independently associated with relatively lower weight gain at follow-up [749].

Summary

489. Methodological constraints are a severe limitation in defining the role of diet composition on the regulation of body weight. Overall, the evidence of diet composition affecting risk of

weight gain is weak, despite energy intakes clearly being fundamental to weight gain.

490. Surveys suggest that diet macronutrient composition has changed over the past 20 years or more, with an increased proportion of energy from carbohydrate and a decreased proportion from total fat and saturated fatty acids. This was over the same time period in which there has been a large increase in the prevalence of those overweight and obese. There also appears to have been a decrease in average daily energy intakes, which appears to date from the 1960s, and which may reflect a decrease in energy expenditure during this time.

491. With regard to the regulation of body weight, it is important to consider diet in conjunction with physical activity. Consideration of energy balance and flux is required, rather than just energy intake and expenditure in isolation. This is the topic of the following appendix.

Appendix 8. A consideration of energy intake and physical activity in relation to weight gain

Background

492. As weight gain is dependent on energy intake and energy expenditure, it is necessary to consider energy balance and energy flux, rather than energy intake and energy expenditure in isolation. This is the focus of the current appendix.

493. It is not possible to accurately define a level of energy expenditure or a required frequency, intensity and duration of physical activities that reduces the risk of weight gain. Available evidence suggests the influence of physical activity on body weight is weak, although methodological constraints are clearly an issue in interpreting the data [106].

494. The evidence investigating whether diet composition affects risk of weight gain is also weak [623], but clearly a mismatch between energy intakes and energy expenditure is fundamental to weight gain. Methodological constraints have hampered elucidating the role of physical activity and diet composition in the development of overweight and obesity. Weight gain and obesity must result from a chronic positive energy imbalance, which implies a failure of auto-regulatory homeostatic responses to maintain energy balance. The asymmetry between the hunger and satiety arms of human appetite control has been implicated in this process [109].

495. The average daily weight gain in modern populations is relatively small and even in morbidly obese people the lifetime error in daily energy balance regulation is surprisingly small [109]. An analysis of data from national surveys in the US estimated that affecting energy balance by about 420kJ (100 kcal) per day (through change in energy intake and/or PAEE) could prevent weight gain in most of the adult population [621]. In children, a figure of about 1,100kJ (260 kcal) per day, as estimated from body composition changes, was suggested to be necessary to halt weight gain [622].

Energy balance and energy flux

496. It has long since been hypothesised that the mechanisms controlling energy balance may be more accurate in individuals with higher levels of physical activity, but that in sedentary individuals there is a threshold of physical activity below which these mechanisms become imprecise and that this leads to obesity [107]. At low rates of energy flux, or turnover, this dysregulation would lead to a positive energy imbalance [358]. There is some evidence that the coupling between energy expenditure and energy intake may be less efficient at low levels of physical activity [108;109].

497. In metabolic studies lasting between one and two weeks, in which the fat content (and thus the energy density) of foods supplied to volunteers fed *ad libitum* was covertly manipulated [750-752], differences in energy balance were observed between lean subjects confined to whole-body calorimeters, who were less physically active, and those in free-living conditions. For example, when subjects were fed 40% of total energy as fat, those in the calorimeter had a positive energy imbalance of +850 kJ per day and those under free-living conditions had a negative energy imbalance of -1,800kJ per day [109].

498. In another study conducted in a whole-body calorimeter [753], lean subjects fed *ad libitum*, but with the fat content covertly manipulated to 35 or 60% total energy, either undertook planned exercise or remained physically inactive. Over a 2 day period, the active individuals did not have a significantly positive energy imbalance on either diet, but the imposition of sedentary behaviour resulted in a positive energy imbalance that was higher on the high fat diet.

499. A further study conducted over 7 days in a whole-body calorimeter, imposed either a sedentary (1.4 x RMR) or a moderately active (1.8 x RMR) regimen on lean subjects fed *ad libitum* a medium-fat diet and determined the effects on energy balance [754]. There was no significant change in energy intakes across regimens and no tendency for energy intakes to drop as the sedentary regimen progressed, which led to a markedly positive energy imbalance (15.2 MJ over the 7 days) during the sedentary regimen.

500. The existence of a threshold of physical activity below which appetite control is ineffective has been proposed [755]. A prospective DLW study of previously obese women proposed a minimum threshold of PAEE (1.75 TEE:RMR) that was required to maintain weight loss [108], but the evidence for the threshold was not strong [109].

501. While these studies do provide some support for the hypothesis that individuals who had high levels of PAEE are better at balancing energy intake with energy expenditure than those with low levels of PAEE, there are no studies available of a longer duration than one or two weeks; furthermore, the concept of a threshold of energy flux above which regulation is accurate remains unproven.

502. The two ways to increase energy flux are through increased physical activity or through weight gain. Both serve to increase TEE, allowing energy balance to occur at a higher level. If it is easier to maintain energy balance at a high energy flux, this is an important consideration in the treatment of obesity [756]. While physical activity alone appears a relatively inefficient means for losing weight in overweight individuals, it appears to be an important factor in the successful maintenance of weight loss [409]. The efficacy of increased physical activity in maintaining weight loss could be partly due to increasing energy flux; the psychological effects of exercise in enhancing well-being and status and control, and hence compliance with a restrictive dietary regime, may also be important [109].

503. Increasing physical activity leading to increased TEE results either in loss of body weight or to a compensatory increase in energy intake to maintain energy balance. A compensatory increase in energy intake may also result in the increased intake of other food constituents, e.g. minerals and vitamins, thus reducing the risk of nutritional deficiencies and poor nutritional status [757]. Increasing energy flux, by increasing physical activity and while maintaining energy balance, could, therefore, have beneficial nutritional effects apart from any effects on weight maintenance.

Exercise and appetite control

504. There appears to be a spontaneous reduction in hunger associated with participation in exercise programmes [758]. Short (1–2 day)-term and medium (7–16 day)-term physical activity intervention studies show this results in substantial negative energy balances per day [759]. Energy intake subsequently begins to increase and provides compensation for about 30%

of the energy expended in activity. This compensation (up to 16 days) is partial and incomplete; moreover, the extent and degree of compensation appears to vary between individuals [760]. Reducing levels of physical activity was observed not to result in a compensatory reduction of energy intake, leading to a positive energy imbalance, in lean men over 7 days [754].

505. It seems, therefore, that it might take considerable time for energy intake to adjust to changes in energy expenditure. Some studies indicate that short-term exercise does not have the same effect on food intake as long-term exercise and that eventual increase in food intake due to increased physical activity does not follow the same pattern in obese as in lean individuals [757].

506. There is some evidence to suggest exercise may modulate appetite control by improving the sensitivity of the physiological satiety signalling system [759;761;762]. Compensation for a high-carbohydrate preload was observed to be more accurate in habitual exercisers than non-exercisers [763], as well as in those who had completed a 6-week moderate-intensity exercise intervention [35]. Following a bout of exercise, subjects were observed to discriminate more accurately between the energy values of different beverages [764].

507. Overall, individuals appear to tolerate substantial exercise-induced negative energy balances, for which compensation in energy intake is incomplete by 16 days [754]. Physical inactivity resulted in a positive energy imbalance, for which there was no compensation in energy intake after seven days.

Summary

508. While it may not be possible to accurately define the nature of the relationship between physical activity, diet and weight gain, it is clear that both physical activity and a balanced diet have important roles in the provision of health in general.

509. It is important for further research to consider the potential interaction of diet composition and physical activity in the development and maintenance of obesity. Most previous research has focused exclusively on the effects of one type of diet or of physical activity or examined diet composition and physical inactivity independently, but few studies have compared the effects of a combination of diet composition and physical activity. Any effect of diet composition may be dependent on the pattern of physical activity. Conversely, any effect of physical activity may depend, in part, on diet composition. A better understanding of these two factors and their relation may help explain why obesity is so prevalent in the UK, while allowing for the fact that not everyone within that environment is obese.

Appendix 9. Characteristics of the data set of DLW measures of energy expenditure of children adolescents and teenagers

510. The available DLW data from studies of children aged >1 year was examined. A data set of 845 individual values was assembled for the US DRI report[20], probably limited to studies published before 2002. The distribution by age was uneven and included large numbers of infants aged<2, 4-5 and 8-10 year olds, with fewer 2-3 and 10-18 year olds.

511. The FAO/WHO/UNU report was based on studies assembled by Torun[765] which were listed in terms of mean study values for children aged >1 year. This involved many more individual children with a more even age spread than that examined in the US DRI report[20].

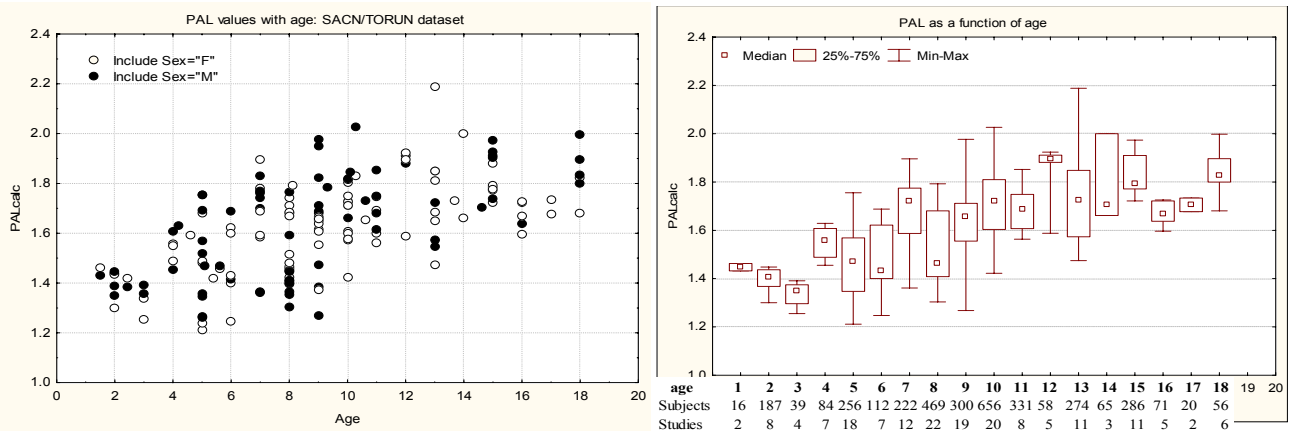
512. SACN compiled a data set of all published DLW studies of children aged >1 year which included all those studies assembled by Torun[765] and other studies published up to 2006[277;766-768;768-783]. All studies were tabulated according to study mean values for boys and girls for specific age groups. This resulted in 170 data points (study means) representing a total of 3502 individual measurements (females=2082, males=1420). They included 4 studies from developing countries (Brazil, Chile, Guatemala and Mexico) but all were well nourished. The rest were mainly from the United Kingdom or the United States of America with single studies from Canada, Denmark, the Netherlands and Sweden. Those from the USA involved Caucasian-American, African- American and native-American children.

513. PAL values and BMR values were not included in many of the studies. For all studies which did not report BMR, BMR values were calculated from the Henry equations for weight and height or just weight if no height was reported. PAL values were then calculated from TEE and BMR.

Number of studies and individuals within the studies and general characteristics.

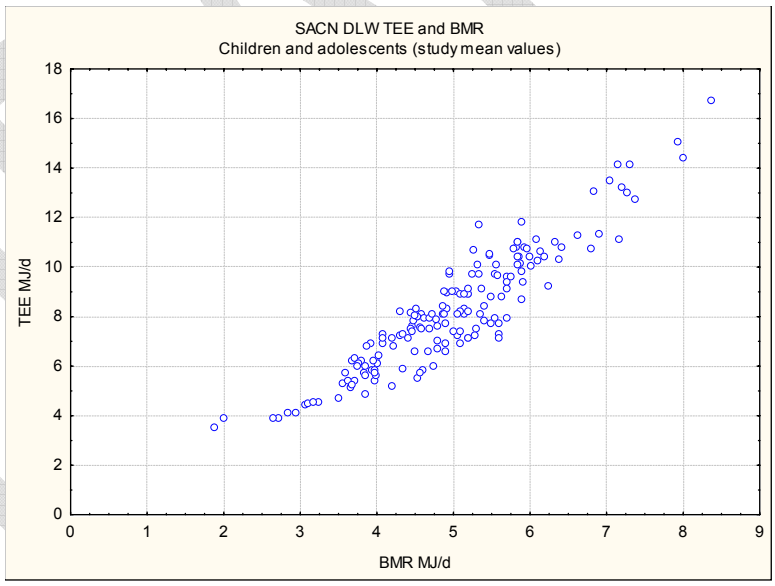
514. Values are shown in Figure 8. The tabulated data will be made available on the SACN website. The data set includes a reasonable overall age spread in terms of number of studies, although there are 5 or less studies for ages of 3,11,13,15 and 16 years. Thus there were relatively few subjects studied at the ages of 3,4,12, 14, 16-18 years and an excess of subjects (>600) at 10 years of age. Older teenagers (>15 years of age) are under-represented. Although most data points do relate to discreet age groups, in some cases data points are the mean of an age range. For example three data points for 8 year olds include PAL values from a total of 149 children with ages from 5-10.5 years.

Figure 8. Mean PAL study values in the SACN data set as a function of age and gender and



515. The regression of TEE on BMR is shown in Figure 9. The increase in PAL after the age of 4 means that the slope of the regression of TEE on BMR increases after this time. This is discussed in more detail in Appendix 2.

Figure 9. Regression of TEE on BMR: SACN children's data set



Grouping by age

516. Overall, PAL appears to increase with age (see Figure 9) from 1.33 to1.81 between the ages of 1 and 18 years, as indicated by a polynomial (quadratic) regression (see Figure 10). However there was a clustering of the youngest children (age1-3 years) at the lower range (PAL ≈ 1.4), with an increase in the overall range starting at school age and with fewer studies with mean PAL values below 1.6 (n= 2) in teenagers. From an early age (≅5 years) there is a wide range of mean study PAL values for boys and girls around the regression. This suggests that grouping into three age groups would be a valid way of expressing the

increase in PAL with age, thereby simplifying the calculation of energy reference values for children and adolescents.

517. Grouping of PAL values within the ages for which BMR is estimated (i.e.1-3, 3-<10 and 10-18 years) is shown in Figure 10 and Table 36. Median PAL values for the three age groups are 1.39 (≤3 years), 1.57 (>3-<10 years) and 1.73 (>10-18 years). For the age groups ≤3 years and >10-18 years and for the ages of 5.5-8 years, the median values fall within or close to the 95th CI values of the regression. Clearly the step changes in PAL and consequent energy reference values at the age group boundaries are a disadvantage to this approach which needs to be balanced against the simplifying effect of not using age specific PAL values predicted from the regression.

Figure 10. Grouping of PAL values by ages 0–3, >3–<10 and >10–18 years (SACN children's data set)

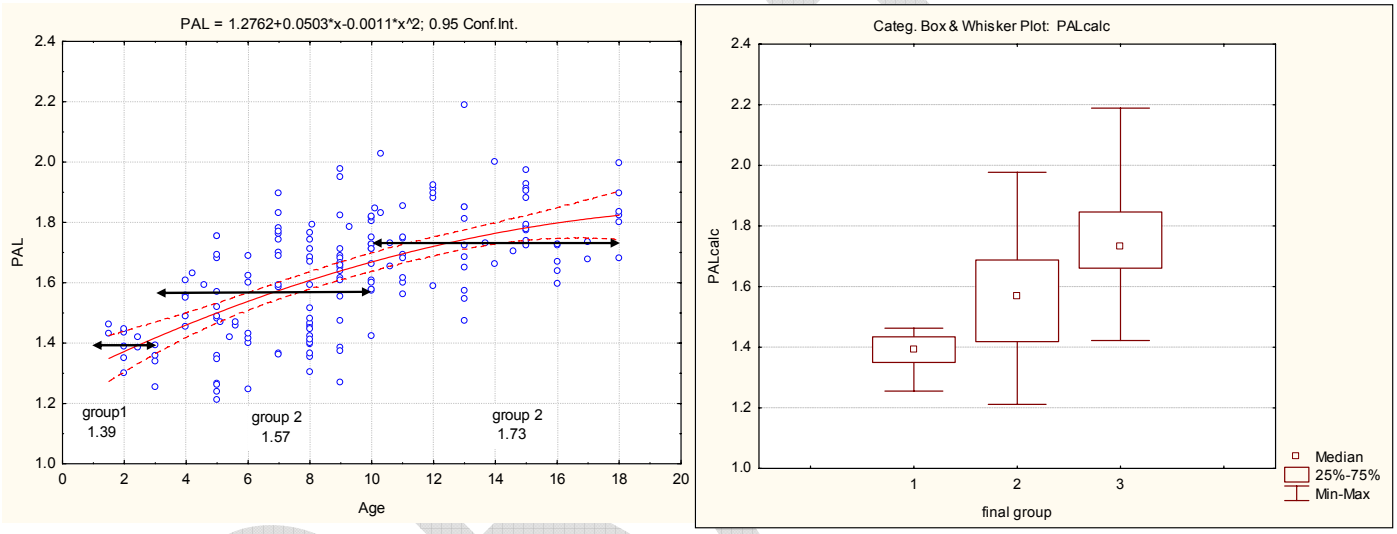


Table 36. Grouping of PAL values within the ages ≤3, >3-<10 and 10-18 years (SACN children's data set)

		Age				PAL						
	N	mean	sd	Min	Max	mean	sd	Min	Max	Q25	**Median**	Q75
1	14	2.3	0.54	1.5	3.0	1.39	0.06	1.26	1.46	1.35	**1.39**	1.43
2	85	7.0	1.87	4.0	9.3	1.56	0.14	1.21	1.98	1.42	**1.57**	1.69
3	71	13.0	2.38	10.0	18.0	1.75	0.13	1.42	2.19	1.66	**1.73**	1.85

Influence of gender

518. Factorial ANOVA of PAL by age group and gender shows that gender is not a significant influence on PAL but there are significant differences between each of the three age groups.

Table 37. Influences of gender on PAL values within the ages1-3,>3-<10 and 10-18

Gender			Age		PAL			
	Group	N	Means	Std.Dev.	Means	Std.Dev.	P values	
Girls	1	5	2.0	0.34	1.41	0.06	Gender	0.28
	2	23	5.4	1.23	1.50	0.18	Group	<0.0001
	3	63	11.2	2.94	1.67	0.15	Gender x group	0.55
Boys	1	5	2.0	0.34	1.40	0.04		
	2	25	5.4	1.24	1.54	0.18		
	3	49	11.5	3.19	1.71	0.20		

Variation of PAL with age within the BMR age groups.

519. PAL varies with age within both the 3-<10 and 10-18 age groups but the influence of age is minor compared with the overall variability (r^2=0.098 and 0.057) especially in the 10-18 group (p=0.04). The slopes imply increases in PAL of 0.14 and 0.1 PAL units respectively over the age ranges, a very small change compared with the wide within group overall range as shown above.

520. It is by no means certain that the changes with age for school age children are real or reflect selection bias or other between study factors. An analysis of the data set by DLW methodology (multipoint, two point or other) indicate that the PAL values for those involving the two point method, are almost invariably lower (≈ 0.2 PAL units) than the other methodologies. Because these studies represent a considerable fraction of studies on children from 5-9 years but relatively few involve teenagers, their inclusion in the data set does tend to increase the age-related changes in PAL. However as discussed in Appendix 1, although some reviewers suggest that the multipoint approach may decrease the error to a small degree, overall the different approaches are in principle equally valid.

521. Examination of the few studies which report the range of PAL values in randomly selected pre-adolescent school children shows that such children do exhibit the same wide range of physical activity as the adult population. Thus in a study of 47 randomly selected Australian school children, aged 5–10.5 years, PAL varied from 1.32-2.18 (mean =1.71) with tertiles of 1.32-1.63, 1.64-1.80, 1.81-2.18[475]. The same group report mean PAL values of a group of 106 school children aged 6.0–9.6 years[477] which varied over a very wide range 1.2-2.32, mean = 1.70. The combined data from these two studies (n=149) indicate a median PAL of 1.69 (range 1.19-2.34, 25th and 75th centiles of 1.56 and 1.83) with ages from 5-10.5 years. Although individual PAL values are not shown as a function of age the authors analysis of variation in PAL values (in relation to adiposity), implies that age was not an influence.

Adjustment of PAL to account for growth costs

522. Actual growth costs calculated by SACN differ only slightly from those reported by FAO/WHO/UNU[13]. In the US DRI report[20] a simplified estimate is reported with single values for the 3-7 and 8-18 year age groups. Within the FAO report[13] growth costs are also reported as an adjustment to average PAL values involving an increase of 1%, i.e. an

assumption that growth costs (deposition) are equivalent to 1% of the energy requirement (ER).

523. It is the case that if growth costs are calculated as a percentage of ER the values indicated are an overall average (1-16 years) of 0.98% of ER (range, boys: 0.4% - 1.37%; girls: 0.05% - 1.59% girls). If a single average growth value as a percentage of ER was used throughout the age range, the maximum errors would be during the peak growth phase for older children where growth would be underestimated by up to 0.6% ER for girls or 0.4% for boys and then overestimated by similar amounts as growth slows at the end of teenage years. These are trivial amounts (i.e. 0.01PAL units), given the variation in PAL and overall TEE which occurs at all ages.

524. Thus growth costs can be included within a factorial model as an adjustment to PAL values of an increase of 1% (i.e. =1.01 x PAL).

Table 38. PAL values for use in calculation of energy requirements of children and adolescents, adjusted for growth

Age group	PAL*		
mean	Q25	**Median**	Q75
1-3	1.36	**1.40**	1.45
>3-<10	1.43	**1.58**	1.70
10-18	1.68	**1.75**	1.86

** PAL as indicated in Table 36 adjusted for growth(=PALx1.01)*

Appendix 10. Characteristics of the data set of DLW measures of energy expenditure for adults: combined OPEN/Beltsville DLW data set.

525. The two data sets of total energy expenditure (TEE) measures used were the OPEN study [60;61] (individual data obtained from Amy Subar) and the Beltsville underreporting study [62] (individual data obtained from Alanna Moshfegh).

526. The OPEN study (n=450) involved healthy volunteers aged 40–69 years recruited from a random sample of 5000 households in the metropolitan area of Washington, DC (Montgomery County, MD). The cohort comprised 245 men and 206 women, 85% were white with the rest mainly black or Asian. Most (87%) had some college schooling with 63% college graduates or post graduates. The distribution by BMI groups was 31% normal (18.5 to less than 25 kg/m^2), 41% overweight (25 to less than 30 kg/m^2), and 29% obese (30 kg/m^2 or more).

527. BMR was not measured in the OPEN study, but BMR was estimated using the Mifflin predictions based on weight, height and age [61]. For reasons discussed in Appendix 3, the data presented here are calculated using the Henry prediction equations based on weight and height [57].

528. The Beltsville study (n= 525) involved a study cohort of volunteers aged 30–69 years residing in the greater Washington, DC, metropolitan area. These were recruited through advertisements in local newspapers and on websites; announcements sent to employees of USDA (Beltsville, MD), local industries, and offices; and the use of a Beltsville Human Nutrition Research Center database of persons known to be interested in participating in human studies.

529. The subjects were predominately non-Hispanic white and were distributed evenly by sex and approximately by age. Only 8% of subjects had not attended college. Approximately 21% of the subjects (both sexes) were obese (BMI greater than 30). More females (48%) than males (36%) were considered normal weight. Only 5% of the men and 6% of the women were current smokers. BMR was measured.

530. The characteristics of the distribution of the PAL values for the two data sets are shown in Table 39. They were clearly very similar. The combined Beltsville and OPEN data set was trimmed for PAL values less than 1.27 or greater than 2.5, on the grounds that these are the limits of sustainable PAL values within a healthy population and that values outside this range are unphysiological, mainly due to measurement error. This removed 1 subject with a PAL value greater than 2.5 and 38 subjects with PAL values less than1.27 (mean 1.17, range 1.01- 1.269). The effect of trimming was to increase the median PAL value from 1.62 to 1.63 (see Table 39).

Table 39. PAL value statistics for individual and combined OPEN[60;61] and BELTSVILLE[62] data sets

PAL	n	Mean	SD	Min	10th centile	25th centile	Median centile	75th centile	90th centile	Max
Beltsville	478	1.63	0.25	1.01	1.32	1.46	1.62	1.78	1.96	2.34
OPEN	451	1.64	0.21	1.01	1.40	1.49	1.61	1.77	1.92	2.61
All	929	1.64	0.23	1.01	1.36	1.48	1.62	1.78	1.95	2.61
Trimmed	890	1.66	0.21	1.27	1.40	1.49	1.63	1.78	1.96	2.50

531. The distribution of PAL by gender and age, and in terms of frequency, is shown in Figure 11. The distribution of subjects by BMI and age is shown in Figure 12. The regression of TEE on BMR is shown in Figure 13 indicating the very small intercept (33.5 kcal/kg (95% CI:-104 & 171; p=0.6), which is discussed further in Appendix 2.

Figure 11. Distribution of PAL by gender and age and frequency

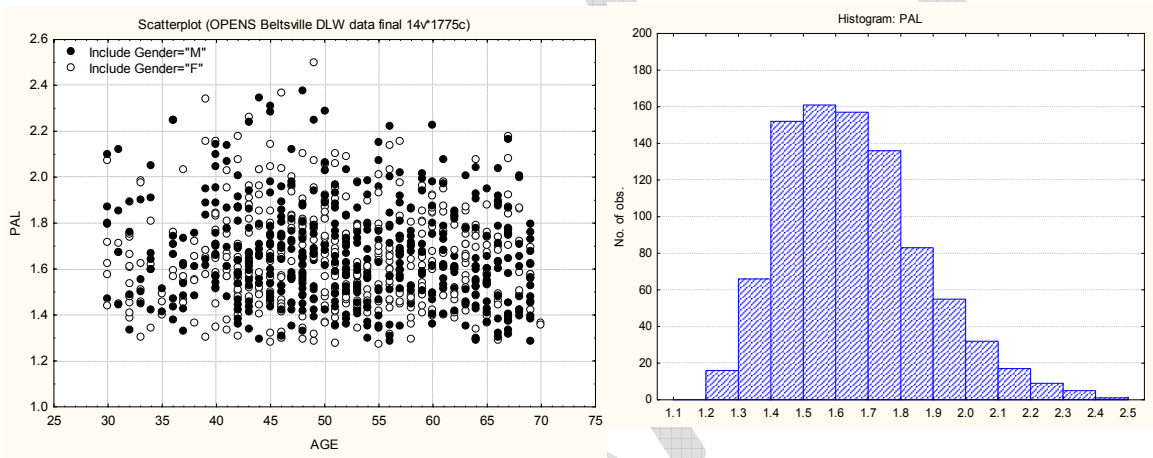


Figure 12. Distribution of subjects by BMI and age.

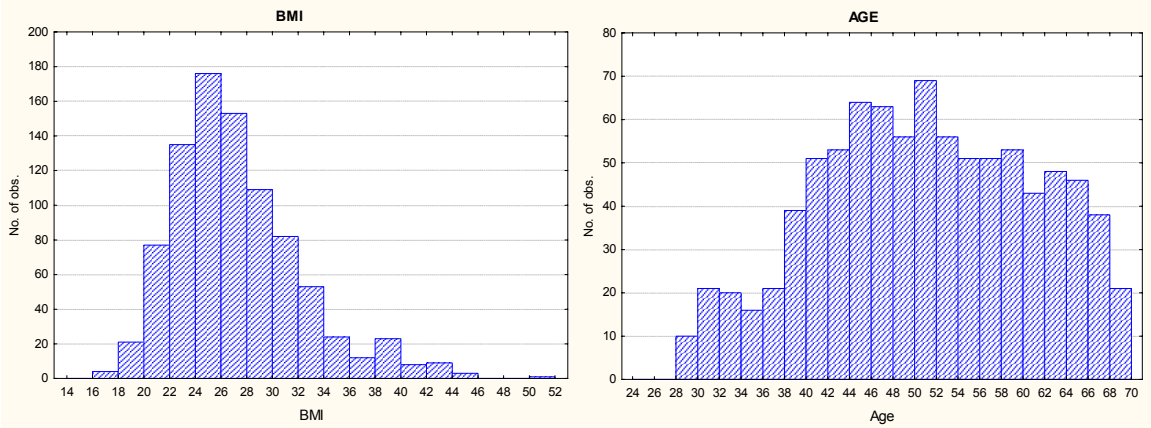
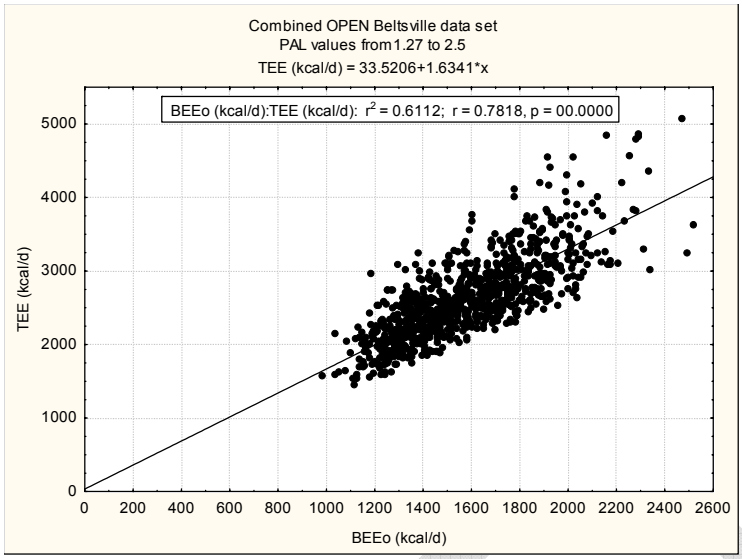


Figure 13. Regression of TEE on BMR: Adult data set



532. The population demographics are shown in Table 40, and the distribution of BMI and its relationship to PAL is shown in Table 42 and Table 43.

Table 40. Population demographics for combined OPEN and BELTSVILLE data sets

		n	Mean	sd	Min	Max
AGE	F	424	51	10	30	70
y	M	466	52	10	30	69
	All Grps	890	51	10	30	70
Height*	F	206	1.63	0.06	1.47	1.82
m	M	239	1.77	0.07	1.58	1.94
	All Grps	445	1.70	0.10	1.47	1.94
Weight*	F	206	73	17	45	126
kg	M	239	88	16	54	138
	All Grps	445	81	18	45	138
BMI	F	424	27	6	17	51
kg/m2	M	466	28	4	18	43
	All Grps	890	27	5	17	51
BMR	F	424	1393	166	982	1960
kcal/d	M	466	1757	217	1279	2522
	All Grps	890	1584	266	982	2522
TEE	F	424	2290	386	1442	3731
kcal/d	M	466	2923	516	1889	5061
	All Grps	890	2621	557	1442	5061

*Beltsville data set contains only BMI, not height or weight

Table 41. Distribution of BMI and its relationship to PAL for the combined OPEN and BELTSVILLE data sets

			BMI		PAL				
		N	mean	sd	mean	sd	median	Min	Max
Normal	All	322	22.7	1.69	1.65	0.21	1.61	1.27	2.37
	Female	181	22.4	1.76	1.64	0.22	1.60	1.27	2.37
	Male	141	23.1	1.51	1.67	0.21	1.64	1.29	2.34
overweight	All	348	27.2	1.45	1.66	0.20	1.65	1.29	2.50
	Female	136	27.1	1.41	1.66	0.21	1.63	1.29	2.50
	Male	212	27.3	1.47	1.66	0.20	1.66	1.29	2.31
Obese	All	220	34.1	3.94	1.66	0.23	1.63	1.28	2.37
	Female	107	34.7	4.37	1.65	0.21	1.63	1.28	2.15
	Male	113	33.5	3.41	1.67	0.24	1.63	1.29	2.37
All		890	27.3	4.97	1.66	0.21	1.63	1.27	2.50

Table 42. Distribution of PAL according to BMI categories for the combined OPEN and BELTSVILLE data sets

Status	N	Mean	Std.Dev.	Minimum	10th	Q25	Median	Q75	90th	Maximum
Normal	322	1.65	0.21	1.27	1.40	1.49	1.61	1.78	1.95	2.37
Overweight	348	1.66	0.20	1.29	1.41	1.50	1.65	1.79	1.92	2.50
Obese	220	1.66	0.23	1.28	1.40	1.47	1.63	1.80	1.99	2.37
All	890	1.66	0.21	1.27	1.40	1.49	1.63	1.78	1.96	2.50

533. Within the cohort, there were similar numbers of overweight and obese subjects (36% normal, 39% overweight and 25% obese). Mean PAL values for BMI categories did not differ significantly (p=0.91) neither did the distribution in terms of quartile boundaries and 10^{th} and 90^{th} centile values. Also the regression of PAL on BMI was non-significant (p=0.64 for slope: R^2 less than 0.1%).

161. PAL fell with age (PAL=1.74-0.0016 x age, R^2=0.004, p=<0.03); however, the shallow slope means that the fall with age is small and age explains only 0.4% of the variance, i.e. PAL = 1.69 at 30 and 1.63 at 70. Also as shown in Table 43, a comparison of PAL values between the younger subjects (age≤35y) with those aged >35y shows the absolute values of mean and median PAL values to be slightly lower in the younger subjects, although not significantly different (p=0.51 for mean values). This suggests that the lack of adult subjects aged <30 is unlikely to represent a significant source of bias when the data set is used to represent PAL values for all adults.

Table 43. Comparison of PAL values between the youngest group (aged<=35) with those >35y

age	N	Mean	Std.Dev.	Minimum	10^{th} centile	Q25	Median	Q75	90^{th} centile	Maximum
≤35	56	1.64	0.21	1.30	1.41	1.46	1.61	1.78	1.97	2.12
>35	834	1.66	0.21	1.27	1.40	1.49	1.63	1.78	1.96	2.50

Appendix 11. Comparisons with previous reports.

534. Table 44 shows energy reference values for infants, children and adolescents in the current report based on median PAL values for the various age groups compared with values reported by COMA[1], with the change in this report shown as a percentage. The values reported by COMA are those most likely to have been used and were interpolated from more detailed tables. They can be compared with similarly interpolated values from the current report. Some of the body weights at the various ages used to calculate values in the two reports vary slightly and this explains some of the differences although most are due to the different methods of calculation. The overall pattern of differences is for an increase in the EAR value for newborn infants, lower values from 3 months to 10 years, with higher values for adolescents especially girls.

Table 44. Energy reference values for infants, children and adolescents in the current report compared with values reported by COMA[1]

Age	Energy reference values (MJ/d)					
	COMA (1991)		SACN 2009		Change (±%)	
	Boys	Girls	Boys	Girls	Boys	Girls
0-3 months	2.3	2.2	2.6	2.4	14	10
3-6 months	2.9	2.7	2.7	2.5	-8	-7
6-9 months	3.4	3.2	2.9	2.7	-15	-16
10-12 months	3.9	3.6	3.2	3.0	-16	-18
1-3 years	5.2	4.9	4.3	4.1	-16	-16
4-6 years	7.2	6.5	6.2	5.8	-14	-10
7-10 years	8.2	7.3	7.6	7.2	-7	-1
11-14 years	9.3	7.9	9.8	9.1	6	15
15-18 years	11.5	8.8	12.5	10.1	9	14

Infants aged 1-12 months

535. COMA1 defined energy reference values for children aged 0-12 months on the basis of available evidence on TEE for this age group to which estimates of deposited energy during growth were added. This means that energy reference values for infants were only defined for breast milk substitute-fed infants as it was felt that a reference value for breast fed infants was meaningless in practice. The new estimates described here are 10-14% higher at 0-3 months but become progressively lower by up to 18% between 3-12 months.

Children and adolescents aged 1-18 years

536. For 1–3 year old children the new estimates described here are also lower by about 16% compared with the COMA DRV report estimates. This is also the case for older children although the change gets less with age and for adolescents, especially girls, the new reference values are up to 15% higher. For children aged 3-10 years, in the absence of sufficient expenditure data, COMA based its reference values on energy intakes. For older children and adolescents, COMA defined energy reference values with a factorial model as in the present report, with the exception that BMR was predicted by modified Schofield equations. Here

the Henry equations have been used on the basis of arguments elaborated in Appendix 3, but in practice, the predicted BMR values differ only to a minor extent. COMA utilized PAL values ranging from 1.4 to 2.0 and reported reference values for a range of body weights. However, the COMA report did not state which PAL values were used in the final aggregated values (shown in Table 45) or which body weights, although lower PAL values were employed to calculate energy reference values for girls compared to boys. This is why from the age of 7 years, the pattern of change for girls differs from that for boys.

Comparison with FAO/WHO/UNU energy reference values for children and adolescents

537. The FAO/WHO/UNU Human Energy Requirements report[13] uses BMR x PAL to estimate energy reference values for children. BMR was predicted from the Schofield equations. PAL values were derived by dividing TEE values predicted from a polynomial regression of DLW data, by predicted BMR values, adjusting for growth and identifying these PAL values as equivalent to moderate physical activity. This resulted in PAL values increasing from 1.43 at 1-2 years to 1.83 at 17-18 years for boys, and from 1.42 to 1.72 for girls at equivalent ages. These PAL values are generally higher than those identified as median values in the SACN report and therefore the new values derived by SACN are somewhat lower than those identified by FAO/WHO/UNU for moderately active children.

Comparison with COMA DRV report for adults

538. The COMA DRV report values were listed for a range of body weights for men and women aged 19-29 years and 30-59 years based on BMR x PAL, with BMR calculated from modified Schofield equations and with nine PAL values ranging from 1.4 to 2.2 [1]. In the absence of any reliable information, and based on the assumption that much of the population had an inactive lifestyle, the previous energy reference values used a PAL value of 1.4 to calculate the adult population EAR [1]. Subsequent studies suggest that this underestimates population physical activity and consequently a median PAL value 1.63 is recommended for adults in this report, i.e. 16% higher. For a man aged 25-34 years, of an average height and weighing 70.5 kg, the EAR is 11.4 MJ/day while the COMA DRV report is 10.3 MJ/day.

539. This report employs a different approach to identifying specific recommendations for population subgroups, as the prediction of PAL values with the accuracy implied in previous reports is unrealistic. Instead, three broad PAL ranges are defined representing the average or median (PAL=1.63), less active (25th centile: PAL =1.49) or more active (75th centile: PAL=1.78) within the overall range of 1.38-2.5. This means that some sedentary individuals may have energy requirements slightly lower than implied by the less active PAL value and some active individuals may have energy requirements higher than implied by the more active PAL value. Judgements must be made where it is deemed necessary to identify energy requirements more precisely. Such judgements are helped by advice offered about the likely extra energy required for specific activities recognising that these amounts can only be defined approximately.

540. In this report the influence of age on energy requirements is limited to that associated with the change in BMR per kg body weight. The recommendations in terms of PAL values, therefore, are the same for the healthy mobile free living older adults as for younger adults. This is in recognition that an increasing fraction of older adults can and do remain physically active. Evidence suggests that individuals who are able to maintain higher levels of physical

activity of any sort will gain benefit in terms of lower mortality[117]. With an increasing lack of mobility, energy expenditure and requirements will fall so that PAL values at or below the lower quartile will become more appropriate. For those who are immobile, falling food intakes associated with reduced energy requirements increases the potential for nutrient deficiencies so that nutrient dense food becomes particularly important for this population group [1].

541. The COMA DRV report predicted BMR values using modified Schofield equations[1]. Here the Henry equations have been used (see Appendix 3). In practice, however, the predicted BMR values differ only to a minor extent.

Comparison with FAO/WHO/UNU energy intake recommendations for adults

542. The FAO/WHO/UNU Human Energy Requirements report[13] uses BMR x PAL to estimate adult requirements, with BMR calculated from Schofield equations and with six PAL values ranging from 1.45 to 2.20. Here the Henry equations (see Appendix 3), which results in a slightly lower estimation of BMR compared to the Schofield equations.

Table 45. A comparison of the previous and proposed adult population EAR

Men			Weight (kg)			COMA DRV report (PAL=1.40)[a]			EAR (PAL=1.63)[b]		
Age (y)	Height (cm)		BMI 20	22.5	25	BMI 20	22.5	25	BMI 20	22.5	25
19-24	Mean	177	62.7	70.5	78.3	9.3	10.0	10.7	10.7	11.4	12.2
	2.5%ile	163	53.1	59.8	66.4	8.5	9.1	9.6	9.4	10.1	10.7
	97.5%ile	190	72.2	81.2	90.3	10.1	10.9	11.7	11.9	12.8	13.7
25-34	Mean	177	62.7	70.5	78.3	9.6	10.3	11.0	10.7	11.4	12.2
	2.5%ile	165	54.5	61.3	68.1	8.9	9.5	10.1	9.6	10.3	11
	97.5%ile	188	70.7	79.5	88.4	10.3	11.1	11.9	11.7	12.6	13.4
35-49	Mean	176	62.0	69.7	77.4	9.3	9.8	10.3	10.4	11	11.6
	2.5%ile	161	51.8	58.3	64.8	8.6	9.0	9.5	9	9.5	10
	97.5%ile	190	72.2	81.2	90.3	10.0	10.6	11.2	11.7	12.4	13.1
50-64	Mean	175	61.3	68.9	76.6	9.2	9.7	10.3	10.3	10.9	11.5
	2.5%ile	162	52.5	59.0	65.6	8.6	9.1	9.5	9.1	9.6	10.1
	97.5%ile	188	70.7	79.5	88.4	9.9	10.5	11.1	11.5	12.2	12.8
65-74	Mean	172	59.2	66.6	74.0	8.2	8.8	9.3	9.2	9.8	10.4
75+	Mean	169	57.1	64.3	71.4	7.6	8.0	8.3	8.9	9.5	10
Women											
19-24	Mean	163	53.1	59.8	66.4	7.5	8.0	8.6	8.7	9.1	9.6
	2.5%ile	150	45.0	50.6	56.3	6.8	7.2	7.7	7.5	7.9	8.3
	97.5%ile	175	61.3	68.9	76.6	8.2	8.8	9.5	9.7	10.3	10.8
25-34	Mean	162	52.5	59.0	65.6	7.4	8.0	8.5	8.6	9	9.5
	2.5%ile	148	43.8	49.3	54.8	6.7	7.1	7.6	7.4	7.8	8.1
	97.5%ile	172	59.2	66.6	74.0	8.0	8.6	9.3	9.5	10	10.5
35-49	Mean	162	52.5	59.0	65.6	7.5	7.8	8.1	8.4	8.8	9.1
	2.5%ile	151	45.6	51.3	57.0	7.1	7.4	7.7	7.6	7.9	8.3
	97.5%ile	175	61.3	68.9	76.6	7.9	8.2	8.6	9.3	9.8	10.2
50-64	Mean	160	51.2	57.6	64.0	7.4	7.7	8.0	8.3	8.6	9
	2.5%ile	148	43.8	49.3	54.8	7.0	7.3	7.6	7.4	7.7	8
	97.5%ile	173	59.9	67.3	74.8	7.8	8.2	8.5	9.2	9.6	10
65-74	Mean	159	50.6	56.9	63.2	6.8	7.1	7.4	7.6	7.9	8.3
75+	Mean	155	48.1	54.1	60.1	6.4	6.8	7.1	7.3	7.7	8

[a] BMR calculated using the modified Schofield equations [1].
[b] BMR calculated using the Henry equation (see Appendix 3)

Comparison with COMA DRV report for pregnancy

543. The COMA DRV report recommended an increment in EAR of 0.8MJ/d above the pre-pregnant EAR only during the last trimester. It was noted that women who were underweight at the beginning of pregnancy, and women who did not reduce activity, may need more.

Comparison with COMA DRV report for lactation

544. The COMA DRV report for energy recognised two distinctive groups of breastfeeding mothers (see Table 46). Firstly, women who practised exclusive or almost exclusive breastfeeding until the baby was 3-4 months old and then progressively introduce complementary foods as part of an active complementary feeding process which often lasts only a few months (Group 1). Secondly, women who introduced only limited complementary feeds after 3-4 months and whose intention was that breast milk should provide the primary source of nourishment

for 6 months or more (Group 2).

Table 46. Additional energy requirements for lactation

Month	Milk volumes[a] ml/day	Energy cost[b] MJ (kcal)/day	Allowance for weight loss[c] MJ (kcal)/day	Total additional requirement MJ (kcal)/day
All breastfeeding women				
0-1	680	2.38 (570)	- 0.5 (120)	1.9 (450)
1-2	780	2.73 (650)	-0.5 (120)	2.2 (530)
2-3	820	2.87 (690)	-0.5 (120)	2.4 (570)
Group 1				
3-6	700	2.45 (590)	- 0.5 (120)	2.0 (480)
6 onwards	300	1.05 (250)	Nil	1.0 (240)
Group 2				
3-6	750	2.63 (630)	-0.25 (60)	2.4 (570)
6 onwards	650	2.28 (540)	Nil	2.3 (550)

[a] Based on studies from Cambridge and Sweden using the test weighing technique [784;785].
[b] Gross energy density of the milk assumed to be 280 kJ/100 g (67 kcal/100 g). Dietary to milk energy conversion efficiency assumed to be 80 per cent.
[c] Assuming an average weight loss of 500 g/month with an energy equivalence of 29 MJ/kg (6900 kcal/kg).

Reference List

(1) Department of Health. Dietary Reference Values for Food Energy and Nutrients for the United Kingdom. 41. 1991. London, HMSO. Report on Health and Social Subjects.
Ref Type: Report

(2) Finch S, Doyle W, Lowe C, Gregory J, Bates CJ, Prentice A et al. National Diet and Nutrition Survey: people aged 65 years and over. Volume 1: report of the diet and nutrition survey. 1998. London, The Stationary Office.
Ref Type: Report

(3) Gregory J, Bates CJ, Lowe S, Prentice A, Jackson LV, Smithers G et al. National diet and nutrition survey: Young people aged 4 to 18 years: Volume 1: Report of the diet and nutrition survey. Volume 1 ed. London: The Stationery Office, 2000.

(4) Henderson L, Gregory J, Swan G. The National Diet and Nutrition Survey: adults aged 19 to 64 years. Volume 1: Types and quantities of foods consumed. 2002. London, TSO.
Ref Type: Report

(5) Henderson L, Gregory J, Irving K, Swan G. The National Diet and Nutrition Survey: adults aged 19 to 64 years. Volume 2: Energy, protein, carbohydrate, fat and alcohol intake. 2003. London, TSO.
Ref Type: Report

(6) Henderson L, Irving K, Gregory J, Bates CJ, Prentice A, Perks J et al. The National Diet and Nutrition Survey: adults aged 19 to 64 years. Volume 3: Vitamin and mineral intake and urinary
analytes. 2003. London, TSO.
Ref Type: Report

(7) Ruston D, Hoare J, Henderson L, Gregory J, Bates CJ, Prentice A et al. The National Diet and Nutrition Survey: adults aged 19 to 64 years. Volume 4: Nutritional Status (anthropometry and blood analytes), blood pressure and physical activity. 2004. London, TSO.
Ref Type: Report

(8) Hoare J, Henderson L, Bates CJ, Prentice A, Birch M, Swan G et al. The National Diet and Nutrition Survey: adults aged 19 to 64 years. Volume 5: Summary report. 2004. London, TSO.
Ref Type: Report

(9) Nelson MJ, Erens B, Bates B, Church S, Boshier T. Low income diet and nutrition survey. http://www.sacn.gov.uk/pdfs/sacn_07_22_annex_1.pdf . 2007. London, TSO.
Ref Type: Report

(10) Gregory JR, Collins DL, Davies PSW, Hughes JM, Clarke PC. National Diet and Nutrition Survey: children aged 1½-4½ years. Volume 1: report of the

diet and nutrition survey. 1995. London, HMSO.
Ref Type: Report

(11) Gregory J, Foster K, Tyler H, Wiseman M. The Dietary and Nutritional Survey of British Adults. London: HMSO, 1990.

(12) Rennie KL, Coward A, Jebb SA. Estimating under-reporting of energy intake in dietary surveys using an individualised method. Br J Nutr 2007; 97(6):1169-1176.

(13) FAO. Human energy requirements. Report of a Joint FAO/WHO/UNU Expert Consultation. 1. 2004. Rome, FAO. Food and nutrition technical report.
Ref Type: Report

(14) Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 1996; 50(2):72-92.

(15) Black AE. Physical activity levels from a meta-analysis of doubly labeled water studies for validating energy intake as measured by dietary assessment. Nutr Rev 1996; 54(6):170-174.

(16) Scientific Advisory Committee on Nutrition. A framework for the Evaluation of Evidence. http://www.sacn.gov.uk/pdfs/sacn_02_02a.pdf. 2002.
Ref Type: Report

(17) Wareham NJ, Rennie KL. The assessment of physical activity in individuals and populations: why try to be more precise about how physical activity is assessed? Int J Obes Relat Metab Disord 1998; 22 Suppl 2:S30-S38.

(18) Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 1985; 100(2):126-131.

(19) Westerterp KR. Alterations in energy balance with exercise. Am J Clin Nutr 1998; 68(4):970S-974S.

(20) Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Colesterol, Protein, and Amino Acids. 2005. Washington, D.C., National Academy Press.
Ref Type: Report

(21) Speakman JR, Selman C. Physical activity and resting metabolic rate. Proc Nutr Soc 2003; 62(3):621-634.

(22) Ravussin E, Lillioja S, Anderson T, Christin L, Bogardus C. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. J Clin Invest 78, 1562-1578. 1986.
Ref Type: Generic

(23) Zurlo F, Ferraro RT, Fontvielle AM, Rising R, Bogardus C, Ravussin E. Spontaneous physical activity and obesity: cross-sectional and longitudinal studies in Pima Indians. Am J Physiol 1992; 263(2 Pt 1):E296-E300.

(24) Snitker S, Tataranni PA, Ravussin E. Spontaneous physical activity in a respiratory chamber is correlated to habitual physical activity. Int J Obes Relat Metab Disord 2001; 25(10):1481-1486.

(25) Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. Science 1999; 283(5399):212-214.

(26) Levine JA. Nonexercise activity thermogenesis (NEAT): environment and biology. Am J Physiol Endocrinol Metab 2004; 286(5):E675-E685.

(27) Hoyt RW, Friedl KE. Field studies of exercise and food deprivation. Curr Opin Clin Nutr Metab Care 2006; 9(6):685-690.

(28) Westerterp KR, Plasqui G. Physical activity and human energy expenditure. Curr Opin Clin Nutr Metab Care 2004; 7(6):607-613.

(29) Alfonzo-Gonzalez G, Doucet E, Almeras N, Bouchard C, Tremblay A. Estimation of daily energy needs with the FAO/WHO/UNU 1985 procedures in adults: comparison to whole-body indirect calorimetry measurements. Eur J Clin Nutr 2004; 58(8):1125-1131.

(30) Goran MI, Calles-Escandon J, Poehlman ET, O'Connell M, Danforth E Jr. Effects of increased energy intake and/or physical activity on energy expenditure in young healthy men. J Appl Physiol 1994; 77(1):366-372.

(31) Warwick PM. Factorial estimation of daily energy expenditure using a simplified method was improved by adjustment for excess post-exercise oxygen consumption and thermic effect of food. Eur J Clin Nutr 2006; 60(11):1337-1340.

(32) Rothenberg EM, Bosaeus IG, Westerterp KR, Steen BC. Resting energy expenditure, activity energy expenditure and total energy expenditure at age 91-96 years. Br J Nutr 2000; 84(3):319-324.

(33) World Health Organization. Energy and protein requirements. Report of a joint FAO/WHO/UNU expert consultation. 724. 1985. Geneva, WHO. Technical report series.
Ref Type: Report

(34) Vaz M, Karaolis N, Draper A, Shetty P. A compilation of energy costs of physical activities. Public Health Nutr 2005; 8(7A):1153-1183.

(35) Martins C, Truby H, Morgan LM. Short-term appetite control in response to a 6-week exercise programme in sedentary volunteers. Br J Nutr 2007; 98(4):834-842.

(36) Kleiber M. The Fire of Life. An Introduction to Animal Energetics. New

York: Robert E. Krieger Publishing, 1975.

(37) Stratz CH. Der Korper des Kindes. Fur Eltern, Arzta und Kunstler. Ferdinland Enke. Stuttgart: Germany, 1904.

(38) Butte NF, Wong WW, Hopkinson JM, Heinz CJ, Mehta NR, Smith EO. Energy requirements derived from total energy expenditure and energy deposition during the first 2 y of life. Am J Clin Nutr 2000; 72(6):1558-1569.

(39) Tanner JM. Foetus into man: physical growth from conception to maturity. Second ed. Castlemead Publications, Ware, 1990.

(40) Butte NF, Wong WW, Garza C. Energy cost of growth during infancy. Proceedings of the Nutrition Society 1989; 48(02):303-312.

(41) Butte NF, Hopkinson JM, Wong WW, Smith EO, Ellis KJ. Body composition during the first 2 years of life: an updated reference. Pediatr Res 2000; 47(5):578-585.

(42) Butte NF, Wong WW, Treuth MS, Ellis KJ, O'Brian Smith E. Energy requirements during pregnancy based on total energy expenditure and energy deposition. Am J Clin Nutr 2004; 79(6):1078-1087.

(43) Butte NF, King JC. Energy requirements during pregnancy and lactation. Public Health Nutr 2005; 8(7A):1010-1027.

(44) Food Standards Agency. McCance and Widdowson's the composition of foods. 6 ed. Cambridge: Royal Society of Chemistry, 2002.

(45) Schutz Y, Bessard T, Jequier E. Diet-induced thermogenesis measured over a whole day in obese and nonobese women. Am J Clin Nutr 1984; 40(3):542-552.

(46) FAO. Food energy - methods of analysis and conversion factors. Report of a Technical Workshop. 77. 2003. Rome, FAO. Food and Nutrition paper.
Ref Type: Report

(47) Prentice AM. Alcohol and obesity. Int J Obes Relat Metab Disord 1995; 19 Suppl 5:S44-S50.

(48) Schutz Y. Role of substrate utilization and thermogenesis on body-weight control with particular reference to alcohol. Proceedings of the Nutrition Society 2000; 59(04):511-517.

(49) Siler SQ, Neese RA, Hellerstein MK. De novo lipogenesis, lipid kinetics, and whole-body lipid balances in humans after acute alcohol consumption. Am J Clin Nutr 1999; 70(5):928-936.

(50) Raben A, Agerholm-Larsen L, Flint A, Holst JJ, Astrup A. Meals with similar energy densities but rich in protein, fat, carbohydrate, or alcohol have different effects on energy expenditure and substrate metabolism but

not on appetite and energy intake. Am J Clin Nutr 2003; 77(1):91-100.

(51) Schutz Y, Garrow JS. Energy and substrate balance and weight regulation. In: Garrow JS, James WPT, Ralph A, editors. Human nutrition and dietetics. Edinburgh: Churchill Livingstone, 2000: 137-148.

(52) Levine JA. Measurement of energy expenditure. Public Health Nutr 2005; 8(7A):1123-1132.

(53) Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. Hum Nutr Clin Nutr 1985; 39 Suppl 1:5-41.

(54) Schofield C. An annotated bibliography of source material for basal metabolic rate data. Hum Nutr Clin Nutr 1985; 39 Suppl 1:42-91.

(55) James WP. Basal metabolic rate: comments on the new equations. Hum Nutr Clin Nutr 1985; 39 Suppl 1:92-96.

(56) Consensus in Clinical Nutrition. Cambridge University Press, 2004.

(57) Henry CJ. Basal metabolic rate studies in humans: measurement and development of new equations. Public Health Nutr 2005; 8(7A):1133-1152.

(58) Weijs PJ. Validity of predictive equations for resting energy expenditure in US and Dutch overweight and obese class I and II adults aged 18-65 y. Am J Clin Nutr 2008; 88(4):959-970.

(59) Goran MI. Estimating energy requirements: regression based prediction equations or multiples of resting metabolic rate. Public Health Nutr 2005; 8(7A):1184-1186.

(60) Subar AF, Kipnis V, Troiano RP, Midthune D, Schoeller DA, Bingham S et al. Using intake biomarkers to evaluate the extent of dietary misreporting in a large sample of adults: the OPEN study. Am J Epidemiol 2003; 158(1):1-13.

(61) Tooze JA, Schoeller DA, Subar AF, Kipnis V, Schatzkin A, Troiano RP. Total daily energy expenditure among middle-aged men and women: the OPEN Study. Am J Clin Nutr 2007; 86(2):382-387.

(62) Moshfegh AJ, Rhodes DG, Baer DJ, Murayi T, Clemens JC, Rumpler WV et al. The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. Am J Clin Nutr 2008; 88(2):324-332.

(63) Durnin JV. Energy requirements: general principles. Eur J Clin Nutr 1996; 50 Suppl 1:S2-S9.

(64) Prentice AM, Black AE, Coward WA, Cole TJ. Energy expenditure in overweight and obese adults in affluent societies: an analysis of 319 doubly-labelled water measurements. Eur J Clin Nutr 1996; 50(2):93-97.

(65) Das SK, Saltzman E, McCrory MA, Hsu LK, Shikora SA, Dolnikowski G et al. Energy expenditure is very high in extremely obese women. J Nutr 2004; 134(6):1412-1416.

(66) Collins LC, Cornelius MF, Vogel RL, Walker JF, Stamford BA. Effect of caffeine and/or cigarette smoking on resting energy expenditure. Int J Obes Relat Metab Disord 1994; 18(8):551-556.

(67) Elia M. Insights into energy requirements in disease. Public Health Nutr 2005; 8(7A):1037-1052.

(68) Maes HH, Neale MC, Eaves LJ. Genetic and environmental factors in relative body weight and human adiposity. Behav Genet 1997; 27(4):325-351.

(69) Keys A, Fidanza F, Karvonen MJ, Kimura N, Taylor HL. Indices of relative weight and obesity. J Chronic Dis 1972; 25(6):329-343.

(70) Cole TJ, Faith MS, Pietrobelli A, Heo M. What is the best measure of adiposity change in growing children: BMI, BMI %, BMI z-score or BMI centile? Eur J Clin Nutr 2005; 59(3):419-425.

(71) Dietz WH, Robinson TN. Use of the body mass index (BMI) as a measure of overweight in children and adolescents. J Pediatr 1998; 132(2):191-193.

(72) Wells JC, Treleaven P, Cole TJ. BMI compared with 3-dimensional body shape: the UK National Sizing Survey. Am J Clin Nutr 2007; 85(2):419-425.

(73) NICE. Obesity: the prevention, identification, assessment and management of overweight and obesity in adults and children. http://www.nice.org.uk/CG43 . 2006.
Ref Type: Electronic Citation

(74) Pietrobelli A, Faith MS, Allison DB, Gallagher D, Chiumello G, Heymsfield SB. Body mass index as a measure of adiposity among children and adolescents: a validation study. J Pediatr 1998; 132(2):204-210.

(75) Wells JC, Chomtho S, Fewtrell MS. Programming of body composition by early growth and nutrition. Proc Nutr Soc 2007; 66(3):423-434.

(76) Cole TJ. Conditional reference charts to assess weight gain in British infants. Arch Dis Child 1995; 73(1):8-16.

(77) Scientific Advisory Committee on Nutrition. Application of WHO growth standards in the UK. http://www.sacn.gov.uk/pdfs/report_growth_standards_2007_08_10.pdf . 2007.
Ref Type: Electronic Citation

(78) SIGN. Management of obesity in children and young people. 2003. Edinburgh, Scottish Intercollegiate Guidelines Network.
Ref Type: Report

(79) SIGN. Management of obesity in children and young people. 2003. Edinburgh, Scottish Intercollegiate Guidelines Network.
Ref Type: Report

(80) Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 2000; 320(7244):1240-1243.

(81) Cole TJ. Conditional reference charts to assess weight gain in British infants. Arch Dis Child 1995; 73(1):8-16.

(82) Wardle J, Boniface D. Changes in the distributions of body mass index and waist circumference in English adults, 1993//1994 to 2002//2003. Int J Obes 2008; 32(3):527-532.

(83) The Scottish Executive. The Scottish Health Survey 2003: Summary of Key Findings. http://www.scotland.gov.uk/Resource/Doc/924/0019811.pdf . 2005.
Ref Type: Electronic Citation

(84) Statistics for Wales. Welsh Health Survey 2007. http://new.wales.gov.uk/topics/statistics/headlines/health2008/hdw200805291/?lang=en . 2008.
Ref Type: Electronic Citation

(85) Northern Ireland Statistics and Research Agency. Health and Social Wellbeing Survey. Topline results 2005/06. http://www.csu.nisra.gov.uk/survey.asp153.htm . 2006.
Ref Type: Electronic Citation

(86) Haslam D, Sattar N, Lean M. Obesity--time to wake up. BMJ 2006; 333(7569):640-642.

(87) Key TJ, Schatzkin A, Willett WC, Allen NE, Spencer EA, Travis RC. Diet, nutrition and the prevention of cancer. Public Health Nutr 2004; 7(1A):187-200.

(88) Renehan AG, Tyson M, Egger M, Heller RF, Zwahlen M. Body-mass index and incidence of cancer: a systematic review and meta-analysis of prospective observational studies. Lancet 2008; 371(9612):569-578.

(89) Correa A, Gilboa SM, Besser LM, Botto LD, Moore CA, Hobbs CA et al. Diabetes mellitus and birth defects. Am J Obstet Gynecol 2008; 199(3):237-239.

(90) O'Rahilly S, Farooqi IS. Genetics of obesity. Philos Trans R Soc Lond B Biol Sci 2006; 361(1471):1095-1105.

(91) Gerken T, Girard CA, Tung YC, Webby CJ, Saudek V, Hewitson KS et al. The obesity-associated FTO gene encodes a 2-oxoglutarate-dependent nucleic acid demethylase. Science 2007; 318(5855):1469-1472.

(92) Dina C, Meyre D, Gallina S, Durand E, Korner A, Jacobson P et al. Variation in FTO contributes to childhood obesity and severe adult obesity. Nat Genet 2007; 39(6):724-726.

(93) Kring SII, Holst C, Zimmermann E, Jess T, Berentzen T, Toubro S et al. FTO Gene Associated Fatness in Relation to Body Fat Distribution and Metabolic Traits throughout a Broad Range of Fatness. PLoS ONE 2008; 3(8):e2958.

(94) Frayling TM, Timpson NJ, Weedon MN, Zeggini E, Freathy RM, Lindgren CM et al. A common variant in the FTO gene is associated with body mass index and predisposes to childhood and adult obesity. Science 2007; 316(5826):889-894.

(95) Hinney A, Nguyen TT, Scherag A, Friedel S, Bronner G, Muller TD et al. Genome wide association (GWA) study for early onset extreme obesity supports the role of fat mass and obesity associated gene (FTO) variants. PLoS ONE 2007; 2(12):e1361.

(96) Hunt SC, Stone S, Xin Y, Scherer CA, Magness CL, Iadonato SP et al. Association of the FTO gene with BMI. Obesity (Silver Spring) 2008; 16(4):902-904.

(97) Scuteri A, Sanna S, Chen WM, Uda M, Albai G, Strait J et al. Genome-wide association scan shows genetic variants in the FTO gene are associated with obesity-related traits. PLoS Genet 2007; 3(7):e115.

(98) Wardle J, Carnell S, Haworth CM, Farooqi IS, O'Rahilly S, Plomin R. Obesity-associated genetic variation in FTO is associated with diminished satiety. J Clin Endocrinol Metab 2008; 93(9):3640-3643.

(99) Timpson NJ, Emmett PM, Frayling TM, Rogers I, Hattersley AT, McCarthy MI et al. The fat mass-and obesity-associated locus and dietary intake in children. Am J Clin Nutr 2008; 88(4):971-978.

(100) Cecil JE, Tavendale R, Watt P, Hetherington MM, Palmer CNA. An Obesity-Associated FTO Gene Variant and Increased Energy Intake in Children. N Engl J Med 2008; 359(24):2558-2566.

(101) Wardle J, Llewellyn C, Sanderson S, Plomin R. The FTO gene and measured food intake in children. Int J Obes 2009; 33(1):42-45.

(102) Berentzen T, Kring SII, Holst C, Zimmermann E, Jess T, Hansen T et al. Lack of Association of Fatness-Related FTO Gene Variants with Energy Expenditure or Physical Activity. J Clin Endocrinol Metab 2008; 93(7):2904-2908.

(103) Do R, Bailey SD, Desbiens K, Belisle A, Montpetit A, Bouchard C et al. Genetic Variants of FTO Influence Adiposity, Insulin Sensitivity, Leptin Levels, and Resting Metabolic Rate in the Quebec Family Study. Diabetes 2008; 57(4):1147-1150.

(104) Rampersaud E, Mitchell BD, Pollin TI, Fu M, Shen H, O'Connell JR et al. Physical Activity and the Association of Common FTO Gene Variants With Body Mass Index and Obesity. Arch Intern Med 2008; 168(16):1791-1797.

(105) Andreasen CH, Stender-Petersen KL, Mogensen MS, Torekov SS, Wegner L, Andersen G et al. Low Physical Activity Accentuates the Effect of the FTO rs9939609 Polymorphism on Body Fat Accumulation. Diabetes 2008; 57(1):95-101.

(106) Wareham NJ, van Sluijs EM, Ekelund U. Physical activity and obesity prevention: a review of the current evidence. Proc Nutr Soc 2005; 64(2):229-247.

(107) Mayer J, Thomas DW. Regulation of food intake and obesity. Science 1967; 156(773):328-337.

(108) Schoeller DA. Balancing energy expenditure and body weight. Am J Clin Nutr 1998; 68(4):956S-961S.

(109) Prentice AM, Jebb SA. Energy intake/physical activity interactions in the homeostasis of body weight regulation. Nutr Rev 2004; 62(7 Pt 2):S98-104.

(110) Butte NF. Energy requirements of infants. Public Health Nutr 2005; 8(7A):953-967.

(111) Butte NF, Wong WW, Ferlic L, Smith EO, Klein PD, Garza C. Energy expenditure and deposition of breast-fed and formula-fed infants during early infancy. Pediatr Res 1990; 28(6):631-640.

(112) Jiang Z, Yan Q, Su Y, Acheson KJ, Thelin A, Piguet-Welsch C et al. Energy expenditure of Chinese infants in Guangdong Province, south China, determined with use of the doubly labeled water method. Am J Clin Nutr 1998; 67(6):1256-1264.

(113) Dewey KG, Peerson JM, Brown KH, Krebs NF, Michaelsen KF, Persson LA et al. Growth of breast-fed infants deviates from current reference data: a pooled analysis of US, Canadian, and European data sets. World Health Organization Working Group on Infant Growth. Pediatrics 1995; 96(3 Pt 1):495-503.

(114) Whitehead RG, Paul AA. Growth charts and the assessment of infant feeding practices in the western world and in developing countries. Early Hum Dev 1984; 9(3):187-207.

(115) World Health Organization. WHO Child Growth Standards: Methods and development: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. 2006. Geneva, Switzerland, World Health Organization.
Ref Type: Report

(116) Fomom SJ, Haschke F, Ziegler EE, Nelson SE. Body composition of reference children from birth to age 10 years. Am J Clin Nutr 1982;

35(5):1169-1175.

(117) Manini TM, Everhart JE, Patel KV, Schoeller DA, Colbert LH, Visser M et al. Daily Activity Energy Expenditure and Mortality Among Older Adults. JAMA 2006; 296(2):171-179.

(118) Fuller NJ, Sawyer MB, Coward WA, Paxton P, Elia M. Components of total energy expenditure in free-living elderly men (over 75 years of age): measurement, predictability and relationship to quality-of-life indices. Br J Nutr 1996; 75(2):161-173.

(119) World Health Organization. Maternal Anthropometry and Pregnancy Outcomes - A WHO Collaborative Study. Bulletin of the World HealthOrganization 1995; 73:S1-S69.

(120) Hytten FE, Chamberlain G. Clinical physiology in obstetrics. Oxford, United Kingdom: Blackwell Scientific Publications, 1991.

(121) Prentice AM, Goldberg GR. Energy adaptations in human pregnancy: limits and long-term consequences. Am J Clin Nutr 2000; 71(5):1226S-1232.

(122) Prentice AM, Spaaij CJ, Goldberg GR, Poppitt SD, van Raaij JM, Totton M et al. Energy requirements of pregnant and lactating women. Eur J Clin Nutr 1996; 50 Suppl 1:S82-110.

(123) Forsum E, Kabir N, Sadurskis A, Westerterp K. Total energy expenditure of healthy Swedish women during pregnancy and lactation. Am J Clin Nutr 1992; 56(2):334-342.

(124) Goldberg GR, Black AE, Jebb SA, Cole TJ, Murgatroyd PR, Coward WA et al. Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. Eur J Clin Nutr 1991; 45(12):569-581.

(125) Goldberg GR, Prentice AM, Coward WA, Davies HL, Murgatroyd PR, Wensing C et al. Longitudinal assessment of energy expenditure in pregnancy by the doubly labeled water method. Am J Clin Nutr 1993; 57(4):494-505.

(126) Kopp-Hoolihan LE, van Loan MD, Wong WW, King JC. Longitudinal assessment of energy balance in well-nourished, pregnant women. Am J Clin Nutr 1999; 69(4):697-704.

(127) Goldberg GR, Prentice AM, Coward WA, Davies HL, Murgatroyd PR, Sawyer MB et al. Longitudinal assessment of the components of energy balance in well-nourished lactating women. Am J Clin Nutr 1991; 54(5):788-798.

(128) Garza C, Butte NF. Energy concentration of human milk estimated from 24-h pools and various abbreviated sampling schemes. J Pediatr Gastroenterol Nutr 1986; 5(6):943-948.

(129) World Health Organization. Complementary Feeding of Young Children in Developing Countries: A Review of Current Scientific Knowledge. 1998. Geneva, WHO.
Ref Type: Report

(130) Butte NF, Wong WW, Hopkinson JM. Energy requirements of lactating women derived from doubly labeled water and milk energy output. J Nutr 2001; 131(1):53-58.

(131) Lovelady CA, Meredith CN, McCrory MA, Nommsen LA, Joseph LJ, Dewey KG. Energy expenditure in lactating women: a comparison of doubly labeled water and heart-rate-monitoring methods. Am J Clin Nutr 1993; 57(4):512-518.

(132) Institute of Grocery Distribution. Guideline Daily Amounts - Helping consumers make sense of nutritional information on food labels. Institute of Grocery Distribution . 2008.
Ref Type: Electronic Citation

(133) Schoeller DA, Leitch CA, Brown C. Doubly labeled water method: in vivo oxygen and hydrogen isotope fractionation. Am J Physiol Regul Integr Comp Physiol 1986; 251(6):R1137-R1143.

(134) Roberts SB, Dietz W, Sharp T, Dallal GE, Hill JO. Multiple laboratory comparison of the doubly labeled water technique. Obes Res 1995; 3 Suppl 1:3-13.

(135) Trabulsi J, Troiano RP, Subar AF, Sharbaugh C, Kipnis V, Schatzkin A et al. Precision of the doubly labeled water method in a large-scale application: evaluation of a streamlined-dosing protocol in the Observing Protein and Energy Nutrition (OPEN) study. Eur J Clin Nutr 2003; 57(11):1370-1377.

(136) Schoeller DA, Hnilicka JM. Reliability of the doubly labeled water method for the measurement of total daily energy expenditure in free-living subjects. J Nutr 1996; 126(1):348S-354S.

(137) Elia M, Ritz P, Stubbs RJ. Total energy expenditure in the elderly. Eur J Clin Nutr 2000; 54 Suppl 3:S92-103.

(138) Willett WC. Invited Commentary: OPEN Questions. Am J Epidemiol 2003; 158:22-24.

(139) Black AE, Cole TJ. Within- and between-subject variation in energy expenditure measured by the doubly-labelled water technique: implications for validating reported dietary energy intake. Eur J Clin Nutr 2000; 54(5):386-394.

(140) Kipnis V, Subar AF, Midthune D. Structure of dietary measurement error: results of the OPEN biomarker study. Am J Epidemiol 2003; 158:14-21.

(141) NAHRES-4. The Doubly-labelled Water Method for Measuring Energy Expenditure: A consensus Report by the IDECG working group. 1990.

Vienna, IAEA.
Ref Type: Report

(142) Ravussin E, Harper IT, Rising R, Bogardus C. Energy expenditure by doubly labeled water: validation in lean and obese subjects. Am J Physiol 1991; 261(3 Pt 1):E402-E409.

(143) Gibney ER, Murgatroyd P, Wright A, Jebb S, Elia M. Measurement of total energy expenditure in grossly obese women: comparison of the bicarbonate-urea method with whole-body calorimetry and free-living doubly labelled water. Int J Obes Relat Metab Disord 2003; 27(6):641-647.

(144) Carpenter WH, Poehlman ET, O'Connell M, Goran MI. Influence of body composition and resting metabolic rate on variation in total energy expenditure: a meta-analysis. Am J Clin Nutr 1995; 61(1):4-10.

(145) Haggarty P, Valencia ME, McNeill G, Gonzales NL, Moya SY, Pinelli A et al. Energy expenditure during heavy work and its interaction with body weight. Br J Nutr 1997; 77(15):359-373.

(146) Erlichman J, Kerbey AL, James WP. Physical activity and its impact on health outcomes. Paper 2: Prevention of unhealthy weight gain and obesity by physical activity: an analysis of the evidence. Obes Rev 2002; 3(4):273-287.

(147) Levine J. Nonexercise activity thermogenesis-liberating the life-force. J Intern Med 2007; 262(3):273-287.

(148) Yao M, McCrory MA, Ma G, Li Y, Dolnikowski GG, Roberts SB. Energy requirements of urban Chinese adults with manual or sedentary occupations, determined using the doubly labeled water method. Eur J Clin Nutr 2002; 56(7):575-584.

(149) Westerterp KR, Meijer GA, Janssen EM, Saris WH, Ten Hoor F. Long-term effect of physical activity on energy balance and body composition. Br J Nutr 1992; 68(1):21-30.

(150) Bitar A, Fellmann N, Vernet J, Coudert J, Vermorel M. Variations and determinants of energy expenditure as measured by whole-body indirect calorimetry during puberty and adolescence. Am J Clin Nutr 1999; 69(6):1209-1216.

(151) Withers RT, Smith DA, Tucker RC, Brinkman M, Clark DG. Energy metabolism in sedentary and active 49- to 70-yr-old women. J Appl Physiol 1998; 84(4):1333-1340.

(152) Haggarty P, McNeill G, Manneh MK, Davidson L, Milne E, Duncan G et al. The influence of exercise on the energy requirements of adult males in the UK. Br J Nutr 1994; 72(6):799-813.

(153) Davidson L, McNeill G, Haggarty P, Smith JS, Franklin MF. Free-living energy expenditure of adult men assessed by continuous heart-rate

monitoring and doubly-labelled water. Br J Nutr 1997; 78(5):695-708.

(154) Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. J Appl Physiol 2005; 99(3):1112-1119.

(155) Forsum E, Lof M, Schoeller DA. Calculation of energy expenditure in women using the MET system. Med Sci Sports Exerc 2006; 38(8):1520-1525.

(156) Leenders NY, Sherman WM, Nagaraja HN, Kien CL. Evaluation of methods to assess physical activity in free-living conditions. Med Sci Sports Exerc 2001; 33(7):1233-1240.

(157) Bingham SA, Goldberg GR, Coward WA, Prentice AM, Cummings JH. The effect of exercise and improved physical fitness on basal metabolic rate. Br J Nutr 1989; 61(2):155-173.

(158) Arthur PG, Hartmann PE, Smith M. Measurement of the milk intake of breast-fed infants. J Pediatr Gastroenterol Nutr 1987; 6(5):758-763.

(159) Blaak EE, Westerterp KR, Bar-Or O, Wouters LJ, Saris WH. Total energy expenditure and spontaneous activity in relation to training in obese boys. Am J Clin Nutr 1992; 55(4):777-782.

(160) Byrne NM, Weinsier RL, Hunter GR, Desmond R, Patterson MA, Darnell BE et al. Influence of distribution of lean body mass on resting metabolic rate after weight loss and weight regain: comparison of responses in white and black women. Am J Clin Nutr 2003; 77(6):1368-1373.

(161) Wang Z, Heshka S, Gallagher D, Boozer CN, Kotler DP, Heymsfield SB. Resting energy expenditure-fat-free mass relationship: new insights provided by body composition modeling. Am J Physiol Endocrinol Metab 2000; 279(3):E539-E545.

(162) Heymsfield SB, Gallagher D, Kotler DP, Wang Z, Allison DB, Heshka S. Body-size dependence of resting energy expenditure can be attributed to nonenergetic homogeneity of fat-free mass. Am J Physiol Endocrinol Metab 2002; 282(1):E132-E138.

(163) Illner K, Brinkmann G, Heller M, Bosy-Westphal A, Muller MJ. Metabolically active components of fat free mass and resting energy expenditure in nonobese adults. Am J Physiol Endocrinol Metab 2000; 278(2):E308-E315.

(164) Nelson KM, Weinsier RL, Long CL, Schutz Y. Prediction of resting energy expenditure from fat-free mass and fat mass. Am J Clin Nutr 1992; 56(5):848-856.

(165) Johnstone AM, Murison SD, Duncan JS, Rance KA, Speakman JR. Factors influencing variation in basal metabolic rate include fat-free mass, fat mass, age, and circulating thyroxine but not sex, circulating leptin, or triiodothyronine. Am J Clin Nutr 2005; 82(5):941-948.

(166) Muller MJ, Bosy-Westphal A, Klaus S, Kreymann G, Luhrmann PM, Neuhauser-Berthold M et al. World Health Organization equations have shortcomings for predicting resting energy expenditure in persons from a modern, affluent population: generation of a new reference standard from a retrospective analysis of a German database of resting energy expenditure. Am J Clin Nutr 2004; 80(5):1379-1390.

(167) Weinsier RL, Schutz Y, Bracco D. Reexamination of the relationship of resting metabolic rate to fat-free mass and to the metabolically active components of fat-free mass in humans. Am J Clin Nutr 1992; 55(4):790-794.

(168) Cunningham JJ. Body composition as a determinant of energy expenditure: a synthetic review and a proposed general prediction equation. Am J Clin Nutr 1991; 54(6):963-969.

(169) Fukagawa NK, Bandini LG, Young JB. Effect of age on body composition and resting metabolic rate. Am J Physiol 1990; 259(2 Pt 1):E233-E238.

(170) Karhunen L, Franssila-Kallunki A, Rissanen A, Kervinen K, Kesaniemi YA, Uusitupa M. Determinants of resting energy expenditure in obese non-diabetic caucasian women. Int J Obes Relat Metab Disord 1997; 21(3):197-202.

(171) Svendsen OL, Hassager C, Christiansen C. Impact of regional and total body composition and hormones on resting energy expenditure in overweight postmenopausal women. Metabolism 1993; 42(12):1588-1591.

(172) Ferraro R, Ravussin E. Fat mass in predicting resting metabolic rate. Am J Clin Nutr 1992; 56(2):460-461.

(173) Bogardus C, Lillioja S, Ravussin E, Abbott W, Zawadzki JK, Young A et al. Familial dependence of the resting metabolic rate. N Engl J Med 1986; 315(2):96-100.

(174) Segal KR, Gutin B, Albu J, Pi-Sunyer FX. Thermic effects of food and exercise in lean and obese men of similar lean body mass. Am J Physiol 1987; 252(1 Pt 1):E110-E117.

(175) Garby L, Lammert O. Between-subjects variation in energy expenditure: estimation of the effect of variation in organ size. Eur J Clin Nutr 1994; 48(5):376-378.

(176) Gallagher D, Belmonte D, Deurenberg P, Wang Z, Krasnow N, Pi-Sunyer FX et al. Organ-tissue mass measurement allows modeling of REE and metabolically active tissue mass. Am J Physiol 1998; 275(2 Pt 1):E249-E258.

(177) Sparti A, Delany JP, de la Bretonne JA, Sander GE, Bray GA. Relationship between resting metabolic rate and the composition of the fat-free mass. Metabolism 1997; 46(10):1225-1230.

(178) Ekelund U, Yngve A, Brage S, Westerterp K, Sjostrom M. Body movement and physical activity energy expenditure in children and adolescents: how to adjust for differences in body size and age. Am J Clin Nutr 2004; 79(5):851-856.

(179) Johnson RK, Russ J, Goran MI. Physical activity related energy expenditure in children by doubly labeled water as compared with the Caltrac accelerometer. Int J Obes Relat Metab Disord 1998; 22(11):1046-1052.

(180) Roberts SB, Dallal GE. Effects of age on energy balance. Am J Clin Nutr 1998; 68(4):975S-979S.

(181) Rush EC, Plank LD, Coward WA. Energy expenditure of young Polynesian and European women in New Zealand and relations to body composition. Am J Clin Nutr 1999; 69(1):43-48.

(182) Plasqui G, Joosen AM, Kester AD, Goris AH, Westerterp KR. Measuring free-living energy expenditure and physical activity with triaxial accelerometry. Obes Res 2005; 13(8):1363-1369.

(183) Mâsse LC, Fulton JE, Watson KL, Mahar MT, Meyers MC, Wong WW. Influence of body composition on physical activity validation studies using doubly labeled water. J Appl Physiol 2004; 96(4):1357-1364.

(184) Goran MI, Beer WH, Wolfe RR, Poehlman ET, Young VR. Variation in total energy expenditure in young healthy free-living men. Metabolism 1993; 42(4):487-496.

(185) Butte NF, Treuth MS, Mehta NR, Wong WW, Hopkinson JM, Smith EO. Energy requirements of women of reproductive age. Am J Clin Nutr 2003; 77(3):630-638.

(186) Schulz LO, Schoeller DA. A compilation of total daily energy expenditures and body weights in healthy adults. Am J Clin Nutr 1994; 60(5):676-681.

(187) Prentice AM, Goldberg GR, Murgatroyd PR, Cole TJ. Physical activity and obesity: problems in correcting expenditure for body size. Int J Obes Relat Metab Disord 1996; 20(7):688-691.

(188) Goran MI, Kaskoun M, Johnson R. Determinants of resting energy expenditure in young children. J Pediatr 1994; 125(3):362-367.

(189) Kirkby J, Metcalf BS, Jeffery AN, O'Riordan CF, Perkins J, Voss LD et al. Sex differences in resting energy expenditure and their relation to insulin resistance in children (EarlyBird 13). Am J Clin Nutr 2004; 80(2):430-435.

(190) Goran MI, Kaskoun M, Johnson R, Martinez C, Kelly B, Hood V. Energy expenditure and body fat distribution in Mohawk children. Pediatrics 1995; 95(1):89-95.

(191) Ferraro R, Lillioja S, Fontvieille AM, Rising R, Bogardus C, Ravussin E. Lower sedentary metabolic rate in women compared with men. J Clin Invest

1992; 90(3):780-784.

(192) Poehlman ET, Toth MJ, Ades PA, Calles-Escandon J. Gender differences in resting metabolic rate and noradrenaline kinetics in older individuals. Eur J Clin Invest 1997; 27(1):23-28.

(193) Dionne I, Despres JP, Bouchard C, Tremblay A. Gender difference in the effect of body composition on energy metabolism. Int J Obes Relat Metab Disord 1999; 23(3):312-319.

(194) Carpenter WH, Fonong T, Toth MJ, Ades PA, Calles-Escandon J, Walston JD et al. Total daily energy expenditure in free-living older African-Americans and Caucasians. Am J Physiol Endocrinol Metab 1998; 274(1):96-101.

(195) Arciero PJ, Goran MI, Poehlman ET. Resting metabolic rate is lower in women than in men. J Appl Physiol 1993; 75(6):2514-2520.

(196) Blanc S, Schoeller DA, Bauer D, Danielson ME, Tylavsky F, Simonsick EM et al. Energy requirements in the eighth decade of life. Am J Clin Nutr 2004; 79(2):303-310.

(197) Klausen B, Toubro S, Astrup A. Age and sex effects on energy expenditure. Am J Clin Nutr 1997; 65(4):895-907.

(198) Webb P. 24-hour energy expenditure and the menstrual cycle. Am J Clin Nutr 1986; 44(5):614-619.

(199) Day DS, Gozansky WS, Van Pelt RE, Schwartz RS, Kohrt WM. Sex hormone suppression reduces resting energy expenditure and {beta}-adrenergic support of resting energy expenditure. J Clin Endocrinol Metab 2005; 90(6):3312-3317.

(200) Howe JC, Rumpler WV, Seale JL. Energy expenditure by indirect calorimetry in premenopausal women: variation within one menstrual cycle. Journal of Nutritional Biochemistry 1993; 4:268-273.

(201) Meijer GA, Westerterp KR, Saris WH, Ten Hoor F. Sleeping metabolic rate in relation to body composition and the menstrual cycle. Am J Clin Nutr 1992; 55(3):637-640.

(202) Hessemer V, Bruck K. Influence of menstrual cycle on thermoregulatory, metabolic, and heart rate responses to exercise at night. J Appl Physiol 1985; 59(6):1911-1917.

(203) Melanson KJ, Saltzman E, Russell R, Roberts SB. Postabsorptive and postprandial energy expenditure and substrate oxidation do not change during the menstrual cycle in young women. J Nutr 1996; 126(10):2531-2538.

(204) Lariviere F, Moussalli R, Garrel DR. Increased leucine flux and leucine oxidation during the luteal phase of the menstrual cycle in women. Am J

Physiol Endocrinol Metab 1994; 267(3):E422-E428.

(205) Solomon SJ, Kurzer MS, Calloway DH. Menstrual cycle and basal metabolic rate in women. Am J Clin Nutr 1982; 36(4):611-616.

(206) Pelkman CL, Chow M, Heinbach RA, Rolls BJ. Short-term effects of a progestational contraceptive drug on food intake, resting energy expenditure, and body weight in young women. Am J Clin Nutr 2001; 73(1):19-26.

(207) Bisdee JT, James WP, Shaw MA. Changes in energy expenditure during the menstrual cycle. Br J Nutr 1989; 61(2):187-199.

(208) Reimer RA, Debert CT, House JL, Poulin MJ. Dietary and metabolic differences in pre- versus postmenopausal women taking or not taking hormone replacement therapy. Physiol Behav 2005; 84(2):303-312.

(209) Piers LS, Diggavi SN, Rijskamp J, van Raaij JM, Shetty PS, Hautvast JG. Resting metabolic rate and thermic effect of a meal in the follicular and luteal phases of the menstrual cycle in well-nourished Indian women. Am J Clin Nutr 1995; 61(2):296-302.

(210) Kimm SY, Glynn NW, Aston CE, Damcott CM, Poehlman ET, Daniels SR et al. Racial differences in the relation between uncoupling protein genes and resting energy expenditure. Am J Clin Nutr 2002; 75(4):714-719.

(211) Li ET, Tsang LB, Lui SS. Resting metabolic rate and thermic effects of a sucrose-sweetened soft drink during the menstrual cycle in young Chinese women. Can J Physiol Pharmacol 1999; 77(7):544-550.

(212) Diffey B, Piers LS, Soares MJ, O'Dea K. The effect of oral contraceptive agents on the basal metabolic rate of young women. Br J Nutr 1997; 77(6):853-862.

(213) Eck LH, Bennett AG, Egan BM, Ray JW, Mitchell CO, Smith MA et al. Differences in macronutrient selections in users and nonusers of an oral contraceptive. Am J Clin Nutr 1997; 65(2):419-424.

(214) Kyle UG, Genton L, Hans D, Karsegard L, Slosman DO, Pichard C. Age-related differences in fat-free mass, skeletal muscle, body cell mass and fat mass between 18 and 94 years. Eur J Clin Nutr 2001; 55(8):663-672.

(215) Piers LS, Soares MJ, McCormack LM, O'Dea K. Is there evidence for an age-related reduction in metabolic rate? J Appl Physiol 1998; 85(6):2196-2204.

(216) Bosy-Westphal A, Eichhorn C, Kutzner D, Illner K, Heller M, Muller MJ. The Age-Related Decline in Resting Energy Expenditure in Humans Is Due to the Loss of Fat-Free Mass and to Alterations in Its Metabolically Active Components. J Nutr 2003; 133(7):2356-2362.

(217) Kim J, Wang Z, Heymsfield SB, Baumgartner RN, Gallagher D. Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry

method. Am J Clin Nutr 2002; 76(2):378-383.

(218) Roberts SB, Fuss P, Heyman MB, Young VR. Influence of age on energy requirements. Am J Clin Nutr 1995; 62(5 Suppl):1053S-1058S.

(219) Pannemans DL, Westerterp KR. Energy expenditure, physical activity and basal metabolic rate of elderly subjects. Br J Nutr 1995; 73(4):571-581.

(220) Poehlman ET, Melby CL, Badylak SF. Relation of age and physical exercise status on metabolic rate in younger and older healthy men. J Gerontol 1991; 46(2):B54-B58.

(221) Vaughan L, Zurlo F, Ravussin E. Aging and energy expenditure. Am J Clin Nutr 1991; 53(4):821-825.

(222) Visser M, Deurenberg P, Van Staveren WA, Hautvast JG. Resting metabolic rate and diet-induced thermogenesis in young and elderly subjects: relationship with body composition, fat distribution, and physical activity level. Am J Clin Nutr 1995; 61(4):772-778.

(223) Cunningham JJ. A reanalysis of the factors influencing basal metabolic rate in normal adults. Am J Clin Nutr 1980; 33(11):2372-2374.

(224) Das SK, Moriguti JC, McCrory MA, Saltzman E, Mosunic C, Greenberg AS et al. An Underfeeding Study in Healthy Men and Women Provides Further Evidence of Impaired Regulation of Energy Expenditure in Old Age. J Nutr 2001; 131(6):1833-1838.

(225) Wilson MM, Morley JE. Invited Review: Aging and energy balance. J Appl Physiol 2003; 95(4):1728-1736.

(226) Roberts SB, Rosenberg I. Nutrition and Aging: Changes in the Regulation of Energy Metabolism With Aging. Physiol Rev 2006; 86(2):651-667.

(227) Kunz I, Klaus S, Kallies B, Schorr U, Sharma AM. Kinetic analysis of the thermic effect of food and its relationship to body composition in humans. Metabolism 2000; 49(10):1340-1345.

(228) Melanson KJ, Saltzman E, Vinken AG, Russell R, Roberts SB. The effects of age on postprandial thermogenesis at four graded energetic challenges: findings in young and older women. J Gerontol A Biol Sci Med Sci 1998; 53(6):B409-B414.

(229) Bouchard C, Tremblay A, Nadeau A, Despres JP, Theriault G, Boulay MR et al. Genetic effect in resting and exercise metabolic rates. Metabolism 1989; 38(4):364-370.

(230) Dionne IJ, Garant MJ, Nolan AA, Pollin TI, Lewis DG, Shuldiner AR et al. Association between obesity and a polymorphism in the beta(1)-adrenoceptor gene (Gly389Arg ADRB1) in Caucasian women. Int J Obes Relat Metab Disord 2002; 26(5):633-639.

(231) Nagai N, Sakane N, Ueno LM, Hamada T, Moritani T. The -3826 A-->G variant of the uncoupling protein-1 gene diminishes postprandial thermogenesis after a high fat meal in healthy boys. J Clin Endocrinol Metab 2003; 88(12):5661-5667.

(232) Oomen JM, Waijers PM, van Rossum C, Hoebee B, Saris WH, van Baak MA. Influence of beta(2)-adrenoceptor gene polymorphisms on diet-induced thermogenesis. Br J Nutr 2005; 94(5):647-654.

(233) Rissanen J, Kuopusjarvi J, Pihlajamaki J, Sipilainen R, Heikkinen S, Vanhala M et al. The Trp64Arg polymorphism of the beta 3-Adrenergic receptor gene. Lack of association with NIDDM and features of insulin resistance syndrome. Diabetes Care 1997; 20(8):1319-1323.

(234) Rawson ES, Nolan A, Silver K, Shuldiner AR, Poehlman ET. No effect of the Trp64Arg beta(3)-adrenoceptor gene variant on weight loss, body composition, or energy expenditure in obese, caucasian postmenopausal women. Metabolism 2002; 51(6):801-805.

(235) Tchernof A, Starling RD, Walston JD, Shuldiner AR, Dvorak RV, Silver K et al. Obesity-related phenotypes and the beta3-adrenoceptor gene variant in postmenopausal women. Diabetes 1999; 48(7):1425-1428.

(236) Shiwaku K, Nogi A, Anuurad E, Kitajima K, Enkhmaa B, Shimono K et al. Difficulty in losing weight by behavioral intervention for women with Trp64Arg polymorphism of the beta3-adrenergic receptor gene. Int J Obes Relat Metab Disord 2003; 27(9):1028-1036.

(237) Gagnon J, Mauriege P, Roy S, Sjostrom D, Chagnon YC, Dionne FT et al. The Trp64Arg mutation of the beta3 adrenergic receptor gene has no effect on obesity phenotypes in the Quebec Family Study and Swedish Obese Subjects cohorts. J Clin Invest 1996; 98(9):2086-2093.

(238) Hojlund K, Christiansen C, Bjornsbo KS, Poulsen P, Bathum L, Henriksen JE et al. Energy expenditure, body composition and insulin response to glucose in male twins discordant for the Trp64Arg polymorphism of the beta3-adrenergic receptor gene. Diabetes Obes Metab 2006; 8(3):322-330.

(239) Dionne IJ, Turner AN, Tchernof A, Pollin TI, Avrithi D, Gray D et al. Identification of an interactive effect of beta3- and alpha2b-adrenoceptor gene polymorphisms on fat mass in Caucasian women. Diabetes 2001; 50(1):91-95.

(240) Wauters M, Considine RV, Chagnon M, Mertens I, Rankinen T, Bouchard C et al. Leptin levels, leptin receptor gene polymorphisms, and energy metabolism in women. Obes Res 2002; 10(5):394-400.

(241) Stefan N, Vozarova B, Del Parigi A, Ossowski V, Thompson DB, Hanson RL et al. The Gln223Arg polymorphism of the leptin receptor in Pima Indians: influence on energy expenditure, physical activity and lipid metabolism. Int J Obes Relat Metab Disord 2002; 26(12):1629-1632.

(242) Loos RJF, Rankinen T, Chagnon Y, Tremblay A, Perusse L, Bouchard C. Polymorphisms in the leptin and leptin receptor genes in relation to resting metabolic rate and respiratory quotient in the Quebec Family Study. Int J Obes Relat Metab Disord 2006; 30(1):183-190.

(243) Valve R, Heikkinen S, Rissanen A, Laakso M, Uusitupa M. Synergistic effect of polymorphisms in uncoupling protein 1 and beta3-adrenergic receptor genes on basal metabolic rate in obese Finns. Diabetologia 1998; 41(3):357-361.

(244) Oppert JM, Vohl MC, Chagnon M, Dionne FT, Cassard-Doulcier AM, Ricquier D et al. DNA polymorphism in the uncoupling protein (UCP) gene and human body fat. Int J Obes Relat Metab Disord 1994; 18(8):526-531.

(245) Ukkola O, Tremblay A, Sun G, Chagnon YC, Bouchard C. Genetic variation at the uncoupling protein 1, 2 and 3 loci and the response to long-term overfeeding. Eur J Clin Nutr 2001; 55(11):1008-1015.

(246) Klannemark M, Orho M, Groop L. No relationship between identified variants in the uncoupling protein 2 gene and energy expenditure. Eur J Endocrinol 1998; 139(2):217-223.

(247) Walder K, Norman RA, Hanson RL, Schrauwen P, Neverova M, Jenkinson CP et al. Association between uncoupling protein polymorphisms (UCP2-UCP3) and energy metabolism/obesity in Pima indians. Hum Mol Genet 1998; 7(9):1431-1435.

(248) Astrup A, Toubro S, Dalgaard LT, Urhammer SA, Sorensen TI, Pedersen O. Impact of the v/v 55 polymorphism of the uncoupling protein 2 gene on 24-h energy expenditure and substrate oxidation. Int J Obes Relat Metab Disord 1999; 23(10):1030-1034.

(249) Yanovski JA, Diament AL, Sovik KN, Nguyen TT, Li H, Sebring NG et al. Associations between uncoupling protein 2, body composition, and resting energy expenditure in lean and obese African American, white, and Asian children. Am J Clin Nutr 2000; 71(6):1405-1420.

(250) Maestrini S, Podesta F, Di Blasio AM, Savia G, Brunani A, Tagliaferri A et al. Lack of association between UCP2 gene polymorphisms and obesity phenotype in Italian Caucasians. J Endocrinol Invest 2003; 26(10):985-990.

(251) Deriaz O, Dionne F, Perusse L, Tremblay A, Vohl MC, Cote G et al. DNA variation in the genes of the Na,K-adenosine triphosphatase and its relation with resting metabolic rate, respiratory quotient, and body fat. J Clin Invest 1994; 93(2):838-843.

(252) Kim CH, Yun SK, Byun DW, Yoo MH, Lee KU, Suh KI. Codon 54 polymorphism of the fatty acid binding protein 2 gene is associated with increased fat oxidation and hyperinsulinemia, but not with intestinal fatty acid absorption in Korean men. Metabolism 2001; 50(4):473-476.

(253) Sipilainen R, Uusitupa M, Heikkinen S, Rissanen A, Laakso M. Variants in the human intestinal fatty acid binding protein 2 gene in obese subjects. J Clin Endocrinol Metab 1997; 82(8):2629-2632.

(254) Di Blasio AM, van Rossum EF, Maestrini S, Berselli ME, Tagliaferri M, Podesta F et al. The relation between two polymorphisms in the glucocorticoid receptor gene and body mass index, blood pressure and cholesterol in obese patients. Clin Endocrinol (Oxf) 2003; 59(1):68-74.

(255) Kubaszek A, Pihlajamaki J, Punnonen K, Karhapaa P, Vauhkonen I, Laakso M. The C-174G promoter polymorphism of the IL-6 gene affects energy expenditure and insulin sensitivity. Diabetes 2003; 52(2):558-561.

(256) Rutanen J, Pihlajamaki J, Karhapaa P, Vauhkonen I, Kuusisto J, Moilanen ML et al. The Val103Ile polymorphism of melanocortin-4 receptor regulates energy expenditure and weight gain. Obes Res 2004; 12(7):1060-1066.

(257) Krakoff J, Ma L, Kobes S, Knowler WC, Hanson RL, Bogardus C et al. Lower Metabolic Rate in Individuals Heterozygous for Either a Frameshift or a Functional Missense MC4R Variant. Diabetes 2008; 57(12):3267-3272.

(258) Tataranni PA, Baier L, Jenkinson C, Harper I, Del Parigi A, Bogardus C. A Ser311Cys mutation in the human dopamine receptor D2 gene is associated with reduced energy expenditure. Diabetes 2001; 50(4):901-904.

(259) Cai G, Cole SA, Butte NF, Voruganti VS, Comuzzie AG. Genome-wide scan revealed genetic loci for energy metabolism in Hispanic children and adolescents. Int J Obes 2008; 32(4):579-585.

(260) Wu X, Luke A, Cooper RS, Zhu X, Kan D, Tayo BO et al. A genome scan among Nigerians linking resting energy expenditure to chromosome 16. Obes Res 2004; 12(4):577-581.

(261) Norman RA, Tataranni PA, Pratley R, Thompson DB, Hanson RL, Prochazka M et al. Autosomal genomic scan for loci linked to obesity and energy metabolism in Pima Indians. Am J Hum Genet 1998; 62(3):659-668.

(262) Jones A, Jr., Shen W, St Onge MP, Gallagher D, Heshka S, Wang Z et al. Body-composition differences between African American and white women: relation to resting energy requirements. Am J Clin Nutr 2004; 79(5):780-786.

(263) Soares MJ, Piers LS, O'Dea K, Shetty PS. No evidence for an ethnic influence on basal metabolism: an examination of data from India and Australia. Br J Nutr 1998; 79(4):333-341.

(264) Wouters-Adriaens MP, Westerterp KR. Low resting energy expenditure in Asians can be attributed to body composition. Obesity (Silver Spring) 2008; 16(10):2212-2216.

(265) Kushner RF, Racette SB, Neil K, Schoeller DA. Measurement of physical activity among black and white obese women. Obes Res 1995; 3 Suppl

2:261s-265s.

(266) Nicklas BJ, Toth MJ, Goldberg AP, Poehlman ET. Racial Differences in Plasma Leptin Concentrations in Obese Postmenopausal Women. J Clin Endocrinol Metab 1997; 82(1):315-317.

(267) Sun M, Gower BA, Nagy TR, Trowbridge CA, Dezenberg C, Goran MI. Total, resting, and activity-related energy expenditures are similar in Caucasian and African-American children. Am J Physiol 1998; 274(2 Pt 1):E232-E237.

(268) Lawrence M, Thongprasert K, Durnin JV. Between-group differences in basal metabolic rates: an analysis of data collected in Scotland, the Gambia and Thailand. Eur J Clin Nutr 1988; 42(10):877-891.

(269) Albu J, Shur M, Curi M, Murphy L, Heymsfield SB, Pi-Sunyer FX. Resting metabolic rate in obese, premenopausal black women. Am J Clin Nutr 1997; 66(3):531-538.

(270) Forman JN, Miller WC, Szymanski LM, Fernhall B. Differences in resting metabolic rates of inactive obese African-American and Caucasian women. Int J Obes Relat Metab Disord 1998; 22(3):215-221.

(271) Foster GD, Wadden TA, Vogt RA. Resting energy expenditure in obese African American and Caucasian women. Obes Res 1997; 5(1):1-8.

(272) Jakicic JM, Wing RR. Differences in resting energy expenditure in African-American vs Caucasian overweight females. Int J Obes Relat Metab Disord 1998; 22(3):236-242.

(273) Weyer C, Snitker S, Bogardus C, Ravussin E. Energy metabolism in African Americans: potential risk factors for obesity. Am J Clin Nutr 1999; 70(1):13-20.

(274) Kaplan AS, Zemel BS, Stallings VA. Differences in resting energy expenditure in prepubertal black children and white children. J Pediatr 1996; 129(5):643-647.

(275) Morrison JA, Alfaro MP, Khoury P, Thornton BB, Daniels SR. Determinants of resting energy expenditure in young black girls and young white girls. J Pediatr 1996; 129(5):637-642.

(276) Treuth MS, Butte NF, Wong WW. Effects of familial predisposition to obesity on energy expenditure in multiethnic prepubertal girls. Am J Clin Nutr 2000; 71(4):893-900.

(277) Wong WW, Butte NF, Ellis KJ, Hergenroeder AC, Hill RB, Stuff JE et al. Pubertal African-American girls expend less energy at rest and during physical activity than Caucasian girls. J Clin Endocrinol Metab 1999; 84(3):906-911.

(278) Yanovski SZ, Reynolds JC, Boyle AJ, Yanovski JA. Resting metabolic rate

in African-American and Caucasian girls. Obes Res 1997; 5(4):321-325.

(279) Sun M, Gower BA, Bartolucci AA, Hunter GR, Figueroa-Colon R, Goran MI. A longitudinal study of resting energy expenditure relative to body composition during puberty in African American and white children. Am J Clin Nutr 2001; 73(2):308-315.

(280) Chitwood LF, Brown SP, Lundy MJ, Dupper MA. Metabolic propensity toward obesity in black vs white females: responses during rest, exercise and recovery. Int J Obes Relat Metab Disord 1996; 20(5):455-462.

(281) Lovejoy JC, Champagne CM, Smith SR, de Jonge L, Xie H. Ethnic differences in dietary intakes, physical activity, and energy expenditure in middle-aged, premenopausal women: the Healthy Transitions Study. Am J Clin Nutr 2001; 74(1):90-95.

(282) Gannon B, DiPietro L, Poehlman ET. Do African Americans have lower energy expenditure than Caucasians? Int J Obes Relat Metab Disord 2000; 24(1):4-13.

(283) Sharp TA, Bell ML, Grunwald GK, Schmitz KH, Sidney S, Lewis CE et al. Differences in Resting Metabolic Rate between White and African-American Young Adults. Obesity Res 2002; 10(8):726-732.

(284) Foster GD, Wadden TA, Swain RM, Anderson DA, Vogt RA. Changes in resting energy expenditure after weight loss in obese African American and white women. Am J Clin Nutr 1999; 69(1):13-17.

(285) Weinsier RL, Hunter GR, Zuckerman PA, Redden DT, Darnell BE, Larson DE et al. Energy expenditure and free-living physical activity in black and white women: comparison before and after weight loss. Am J Clin Nutr 2000; 71(5):1138-1146.

(286) Hunter GR, Weinsier RL, Darnell BE, Zuckerman PA, Goran MI. Racial differences in energy expenditure and aerobic fitness in premenopausal women1. Am J Clin Nutr 2000; 71(2):500-506.

(287) Tershakovec AM, Kuppler KM, Zemel B, Stallings VA. Age, sex, ethnicity, body composition, and resting energy expenditure of obese African American and white children and adolescents. Am J Clin Nutr 2002; 75(5):867-871.

(288) Gallagher D, Albu J, He Q, Heshka S, Boxt L, Krasnow N et al. Small organs with a high metabolic rate explain lower resting energy expenditure in African American than in white adults. Am J Clin Nutr 2006; 83(5):1062-1067.

(289) Danforth E Jr, Burger A. The role of thyroid hormones in the control of energy expenditure. Clin Endocrinol Metab 1984; 13(3):581-595.

(290) Muller MJ, Burger AG, Ferrannini E, Jequier E, Acheson KJ. Glucoregulatory function of thyroid hormones: role of pancreatic hormones.

Am J Physiol 1989; 256(1 Pt 1):E101-E110.

(291) Bernstein RS, Thornton JC, Yang MU, Wang J, Redmond AM, Pierson RN, Jr. et al. Prediction of the resting metabolic rate in obese patients. Am J Clin Nutr 1983; 37(4):595-602.

(292) Welle S, Jozefowicz R, Statt M. Failure of dehydroepiandrosterone to influence energy and protein metabolism in humans. J Clin Endocrinol Metab 1990; 71(5):1259-1264.

(293) Rosenbaum M, Hirsch J, Murphy E, Leibel RL. Effects of changes in body weight on carbohydrate metabolism, catecholamine excretion, and thyroid function. Am J Clin Nutr 2000; 71(6):1421-1432.

(294) Onur S, Haas V, Bosy-Westphal A, Hauer M, Paul T, Nutzinger D et al. L-Tri-iodothyronine is a major determinant of resting energy expenditure in underweight patients with anorexia nervosa and during weight gain. Eur J Endocrinol 2005; 152(2):179-184.

(295) Obarzanek E, Lesem MD, Jimerson DC. Resting metabolic rate of anorexia nervosa patients during weight gain. Am J Clin Nutr 1994; 60(5):666-675.

(296) Van Wymelbeke V, Brondel L, Marcel Brun J, Rigaud D. Factors associated with the increase in resting energy expenditure during refeeding in malnourished anorexia nervosa patients. Am J Clin Nutr 2004; 80(6):1469-1477.

(297) Astrup A, Buemann B, Christensen NJ, Madsen J, Gluud C, Bennett P et al. The contribution of body composition, substrates, and hormones to the variability in energy expenditure and substrate utilization in premenopausal women. J Clin Endocrinol Metab 1992; 74(2):279-286.

(298) Toubro S, Sorensen TI, Ronn B, Christensen NJ, Astrup A. Twenty-four-hour energy expenditure: the role of body composition, thyroid status, sympathetic activity, and family membership. J Clin Endocrinol Metab 1996; 81(7):2670-2674.

(299) Al Adsani H, Hoffer LJ, Silva JE. Resting Energy Expenditure is Sensitive to Small Dose Changes in Patients on Chronic Thyroid Hormone Replacement. J Clin Endocrinol Metab 1997; 82(4):1118-1125.

(300) Trayhurn P. Biology of leptin--its implications and consequences for the treatment of obesity. Int J Obes Relat Metab Disord 2001; 25 Suppl 1:S26-S28.

(301) Satoh Y, Shimizu T, Lee T, Nishizawa K, Iijima M, Yamashiro Y. Resting energy expenditure and plasma leptin levels in adolescent girls with anorexia nervosa. Int J Eat Disord 2003; 34(1):156-161.

(302) Pauly RP, Lear SA, Hastings FC, Birmingham CL. Resting energy expenditure and plasma leptin levels in anorexia nervosa during acute refeeding. Int J Eat Disord 2000; 28(2):231-234.

(303) Bobbioni-Harsch E, Assimacopoulos-Jeannet F, Lehmann T, Munger R, Allaz AF, Golay A. Leptin plasma levels as a marker of sparing-energy mechanisms in obese women. Int J Obes Relat Metab Disord 1999; 23(5):470-475.

(304) Roberts SB, Nicholson M, Staten M, Dallal GE, Sawaya AL, Heyman MB et al. Relationship between circulating leptin and energy expenditure in adult men and women aged 18 years to 81 years. Obesity Res 1997; 5(5):459-463.

(305) Haas V, Onur S, Paul T, Nutzinger DO, Bosy-Westphal A, Hauer M et al. Leptin and body weight regulation in patients with anorexia nervosa before and during weight recovery. Am J Clin Nutr 2005; 81(4):889-896.

(306) Neuhauser-Berthold M, Herbert BM, Luhrmann PM, Sultemeier AA, Blum WF, Frey J et al. Resting metabolic rate, body composition, and serum leptin concentrations in a free-living elderly population. Eur J Endocrinol 2000; 142(5):486-492.

(307) Nagy TR, Gower BA, Shewchuk RM, Goran MI. Serum Leptin and Energy Expenditure in Children. J Clin Endocrinol Metab 1997; 82(12):4149-4153.

(308) Kennedy A, Gettys TW, Watson P, Wallace P, Ganaway E, Pan Q et al. The metabolic significance of leptin in humans: gender-based differences in relationship to adiposity, insulin sensitivity, and energy expenditure. J Clin Endocrinol Metab 1997; 82(4):1293-1300.

(309) Filozof CM, Murua C, Sanchez MP, Brailovsky C, Perman M, Gonzalez CD et al. Low plasma leptin concentration and low rates of fat oxidation in weight-stable post-obese subjects. Obes Res 2000; 8(3):205-210.

(310) Salbe AD, Nicolson M, Ravussin E. Total energy expenditure and the level of physical activity correlate with plasma leptin concentrations in five-year-old children. J Clin Invest 1997; 99(4):592-595.

(311) Toth MJ, Gottlieb SS, Fisher ML, Ryan AS, Nicklas BJ, Poehlman ET. Plasma leptin concentrations and energy expenditure in heart failure patients. Metabolism 1997; 46(4):450-453.

(312) Jorgensen JO, Vahl N, Dall R, Christiansen JS. Resting metabolic rate in healthy adults: relation to growth hormone status and leptin levels. Metabolism 1998; 47(9):1134-1139.

(313) Mackintosh RM, Hirsch J. The Effects of Leptin Administration in Non-obese Human Subjects. Obesity Res 2001; 9(8):462-469.

(314) Rosenbaum M, Murphy EM, Heymsfield SB, Matthews DE, Leibel RL. Low Dose Leptin Administration Reverses Effects of Sustained Weight-Reduction on Energy Expenditure and Circulating Concentrations of Thyroid Hormones. J Clin Endocrinol Metab 2002; 87(5):2391.

(315) Hukshorn CJ, Menheere PP, Westerterp-Plantenga MS, Saris WH. The effect of pegylated human recombinant leptin (PEG-OB) on neuroendocrine

adaptations to semi-starvation in overweight men. Eur J Endocrinol 2003; 148(6):649-655.

(316) Hukshorn CJ, Westerterp-Plantenga MS, Saris WH. Pegylated human recombinant leptin (PEG-OB) causes additional weight loss in severely energy-restricted, overweight men. Am J Clin Nutr 2003; 77(4):771-776.

(317) Hukshorn CJ, Saris WHM, Westerterp-Plantenga MS, Farid AR, Smith FJ, Campfield LA. Weekly Subcutaneous Pegylated Recombinant Native Human Leptin (PEG-OB) Administration in Obese Men. J Clin Endocrinol Metab 2000; 85(11):4003-4009.

(318) Rosenbaum M, Vandenborne K, Goldsmith R, Simoneau JA, Heymsfield S, Joanisse DR et al. Effects of experimental weight perturbation on skeletal muscle work efficiency in human subjects. Am J Physiol Regul Integr Comp Physiol 2003; 285(1):R183-R192.

(319) Rosenbaum M, Goldsmith R, Bloomfield D, Magnano A, Weimer L, Heymsfield S et al. Low-dose leptin reverses skeletal muscle, autonomic, and neuroendocrine adaptations to maintenance of reduced weight. J Clin Invest 2005; 115(12):3579-3586.

(320) Perkins KA. Metabolic effects of cigarette smoking. J Appl Physiol 1992; 72(2):401-409.

(321) Arciero PJ, Gardner AW, Calles-Escandon J, Benowitz NL, Poehlman ET. Effects of caffeine ingestion on NE kinetics, fat oxidation, and energy expenditure in younger and older men. Am J Physiol 1995; 268(6 Pt 1):E1192-E1198.

(322) Astrup A, Toubro S, Cannon S, Hein P, Breum L, Madsen J. Caffeine: a double-blind, placebo-controlled study of its thermogenic, metabolic, and cardiovascular effects in healthy volunteers. Am J Clin Nutr 1990; 51(5):759-767.

(323) Jessen AB, Toubro S, Astrup A. Effect of chewing gum containing nicotine and caffeine on energy expenditure and substrate utilization in men. Am J Clin Nutr 2003; 77(6):1442-1447.

(324) Perkins KA, Sexton JE, Epstein LH, DiMarco A, Fonte C, Stiller RL et al. Acute thermogenic effects of nicotine combined with caffeine during light physical activity in male and female smokers. Am J Clin Nutr 1994; 60(3):312-319.

(325) Perkins KA, Sexton JE, DiMarco A. Acute thermogenic effects of nicotine and alcohol in healthy male and female smokers. Physiol Behav 1996; 60(1):305-309.

(326) Addolorato G, Capristo E, Greco AV, Stefanini GF, Gasbarrini G. Influence of chronic alcohol abuse on body weight and energy metabolism: is excess ethanol consumption a risk factor for obesity or malnutrition? Journal of

Internal Medicine 1998; 244(5):387-395.

(327) Levine JA, Harris MM, Morgan MY. Energy expenditure in chronic alcohol abuse. Eur J Clin Invest 2000; 30(9):779-786.

(328) Addolorato G, Capristo E, Greco AV, Caputo F, Stefanini GF, Gasbarrini G. Three months of abstinence from alcohol normalizes energy expenditure and substrate oxidation in alcoholics: a longitudinal study. Am J Gastroenterol 1998; 93(12):2476-2481.

(329) Chong PK, Jung RT, Scrimgeour CM, Rennie MJ. The effect of pharmacological dosages of glucocorticoids on free living total energy expenditure in man. Clin Endocrinol (Oxf) 1994; 40(5):577-581.

(330) Tataranni PA, Larson DE, Snitker S, Young JB, Flatt JP, Ravussin E. Effects of glucocorticoids on energy metabolism and food intake in humans. Am J Physiol Endocrinol Metab 1996; 271(2):E317-E325.

(331) Fellows IW, Bennett T, Macdonald IA. The effect of adrenaline upon cardiovascular and metabolic functions in man. Clin Sci (Lond) 1985; 69(2):215-222.

(332) Diepvens K, Westerterp KR, Westerterp-Plantenga MS. Obesity and thermogenesis related to the consumption of caffeine, ephedrine, capsaicin, and green tea. Am J Physiol Regul Integr Comp Physiol 2007; 292(1):R77-R85.

(333) Heal DJ, Aspley S, Prow MR, Jackson HC, Martin KF, Cheetham SC. Sibutramine: a novel anti-obesity drug. A review of the pharmacological evidence to differentiate it from d-amphetamine and d-fenfluramine. Int J Obes Relat Metab Disord 1998; 22 Suppl 1:S18-S28.

(334) Swinamer DL, Phang PT, Jones RL, Grace M, King EG. Effect of routine administration of analgesia on energy expenditure in critically ill patients. Chest 1988; 93(1):4-10.

(335) Dempsey DT, Guenter P, Mullen JL, Fairman R, Crosby LO, Spielman G et al. Energy expenditure in acute trauma to the head with and without barbiturate therapy. Surg Gynecol Obstet 1985; 160(2):128-134.

(336) Wallace JD, Abbott-Johnson WJ, Crawford DHG, Barnard R, Potter JM, Cuneo RC. GH Treatment in Adults with Chronic Liver Disease: A Randomized, Double-Blind, Placebo-Controlled, Cross-Over Study. J Clin Endocrinol Metab 2002; 87(6):2751-2759.

(337) Hansen M, Morthorst R, Larsson B, Flyvbjerg A, Rasmussen MH, Orskov H et al. Effects of 2 wk of GH administration on 24-h indirect calorimetry in young, healthy, lean men. Am J Physiol Endocrinol Metab 2005; 289(6):E1030-E1038.

(338) Jung RT, Shetty PS, James WP. The effect of beta-adrenergic blockade on metabolic rate and peripheral thyroid metabolism in obesity. Eur J Clin

Invest 1980; 10(3):179-182.

(339) Haman F. Shivering in the cold: from mechanisms of fuel selection to survival. J Appl Physiol 2006; 100(5):1702-1708.

(340) Blaza S, Garrow JS. Thermogenic response to temperature, exercise and food stimuli in lean and obese women, studied by 24 h direct calorimetry. Br J Nutr 1983; 49(2):171-180.

(341) Valencia ME, McNeill G, Brockway JM, Smith JS. The effect of environmental temperature and humidity on 24 h energy expenditure in men. Br J Nutr 1992; 68(2):319-327.

(342) Buemann B, Astrup A, Christensen NJ, Madsen J. Effect of moderate cold exposure on 24-h energy expenditure: similar response in postobese and nonobese women. Am J Physiol 1992; 263(6 Pt 1):E1040-E1045.

(343) Westerterp-Plantenga MS, van Marken Lichtenbelt WD, Strobbe H, Schrauwen P. Energy metabolism in humans at a lowered ambient temperature. Eur J Clin Nutr 2002; 56(4):288-296.

(344) van Marken Lichtenbelt WD, Schrauwen P, van de Kerckhove S, Westerterp-Plantenga MS. Individual variation in body temperature and energy expenditure in response to mild cold. Am J Physiol Endocrinol Metab 2002; 282(5):E1077-E1083.

(345) Dauncey MJ. Influence of mild cold on 24 h energy expenditure, resting metabolism and diet-induced thermogenesis. Br J Nutr 1981; 45(2):257-267.

(346) van Marken Lichtenbelt W, Westerterp-Plantenga MS, van Hoydonck P. Individual variation in the relation between body temperature and energy expenditure in response to elevated ambient temperature. Physiol Behav 2001; 73(1-2):235-242.

(347) Warwick PM, Busby R. Influence of mild cold on 24 h energy expenditure in 'normally' clothed adults. Br J Nutr 1990; 63(3):481-488.

(348) Lean ME, Murgatroyd PR, Rothnie I, Reid IW, Harvey R. Metabolic and thyroidal responses to mild cold are abnormal in obese diabetic women. Clin Endocrinol (Oxf) 1988; 28(6):665-673.

(349) Goran MI, Nagy TR, Gower BA, Mazariegos M, Solomons N, Hood V et al. Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: implications for energy requirements. Am J Clin Nutr 1998; 68(3):675-682.

(350) Plasqui G, Kester ADM, Westerterp KR. Seasonal variation in sleeping metabolic rate, thyroid activity, and leptin. Am J Physiol Endocrinol Metab 2003; 285(2):E338-E343.

(351) Plasqui G, Westerterp KR. Seasonal Variation in Total Energy Expenditure and Physical Activity in Dutch Young Adults. Obesity Res 2004; 12(4):688-

694.

(352) World Health Organization. Obesity – Preventing and Managing the Global Epidemic. 894, 17-40. 1998. Geneva, World Health Organization. Technical Report Series.
Ref Type: Report

(353) Royal College of Physicians. Storing up problems: The medical case for a slimmer nation. 2004. London, RCP.
Ref Type: Report

(354) Sesso HD. Invited Commentary: A Challenge for Physical Activity Epidemiology. Am J Epidemiol 2007; 165(12):1351-1353.

(355) Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. Res Q Exerc Sport 2000; 71(2 Suppl):S59-S73.

(356) Rennie KL, Wells JC, McCaffrey TA, Livingstone MB. The effect of physical activity on body fatness in children and adolescents. Proc Nutr Soc 2006; 65(4):393-402.

(357) Wareham NJ, Jakes RW, Rennie KL, Mitchell J, Hennings S, Day NE. Validity and repeatability of the EPIC-Norfolk Physical Activity Questionnaire. Int J Epidemiol 2002; 31(1):168-174.

(358) Blair SN, LaMonte MJ, Nichaman MZ. The evolution of physical activity recommendations: how much is enough? Am J Clin Nutr 2004; 79(5):913S-9920.

(359) Church TS, Earnest CP, Skinner JS, Blair SN. Effects of Different Doses of Physical Activity on Cardiorespiratory Fitness Among Sedentary, Overweight or Obese Postmenopausal Women With Elevated Blood Pressure: A Randomized Controlled Trial. JAMA 2007; 297(19):2081-2091.

(360) Feitosa MF, Gaskill SE, Rice T, Rankinen T, Bouchard C, Rao DC et al. Major gene effects on exercise ventilatory threshold: the HERITAGE Family Study. J Appl Physiol 2002; 93(3):1000-1006.

(361) Ekelund U, Poortvliet E, Nilsson A, Yngve A, Holmberg A, Sjostrom M. Physical activity in relation to aerobic fitness and body fat in 14- to 15-year-old boys and girls. Eur J Appl Physiol 2001; 85(3-4):195-201.

(362) Ekelund U, Franks PW, Sharp S, Brage S, Wareham NJ. Increase in physical activity energy expenditure is associated with reduced metabolic risk independent of change in fatness and fitness. Diabetes Care 2007; 30:2101-2106.

(363) Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study. Diabetologia 2007; 50(9):1832-1840.

(364) Ekelund U, Griffin SJ, Wareham NJ, on behalf of the ProActive Research Group. Physical Activity and Metabolic Risk in Individuals With a Family History of Type 2 Diabetes. Diabetes Care 2007; 30(2):337-342.

(365) Guinhouya CB, Hubert H, Soubrier S, Vilhelm C, Lemdani M, Durocher A. Moderate-to-vigorous physical activity among children: discrepancies in accelerometry-based cut-off points. Obesity (Silver Spring) 2006; 14(5):774-777.

(366) Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Med Sci Sports Exerc 2005; 37(11 Suppl):S523-S530.

(367) Corder K, Brage S, Mattocks C, Ness A, Riddoch C, Wareham NJ et al. Comparison of two methods to assess PAEE during six activities in children. Med Sci Sports Exerc 2007; 39(12):2180-2188.

(368) Department of Health. At Least Five a Week: Evidence on the Impact of Physical Activity and its Relationship to Health. 2004. London, Department of Health.
Ref Type: Report

(369) Nelson MJ, Erens B, Bates B, Church S, Boshier T. Low income diet and nutrition survey. http://www.sacn.gov.uk/pdfs/sacn_07_22_annex_1.pdf . 2007. London, TSO.
Ref Type: Report

(370) The NHS Information Centre. *Statistics on obesity, physical activity and diet: England, February 2009*. 2009. The Health and Social Care Information Centre, Lifestyle Statistics.
Ref Type: Report

(371) The Scottish Executive. The Scottish Health Survey 2003: Summary of Key Findings. http://www.scotland.gov.uk/Resource/Doc/924/0019811.pdf . 2005.
Ref Type: Electronic Citation

(372) Mattocks C, Leary S, Ness A, Deere K, Saunders J, Kirkby J et al. Intraindividual variation of objectively measured physical activity in children. Med Sci Sports Exerc 2007; 39(4):622-629.

(373) Riddoch CJ, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K et al. Objective measurement of levels and patterns of physical activity. Arch Dis Child 2007; 92:963-969.

(374) Riddoch CJ, Bo AL, Wedderkopp N, Harro M, Klasson-Heggebo L, Sardinha LB et al. Physical activity levels and patterns of 9- and 15-yr-old European children. Med Sci Sports Exerc 2004; 36(1):86-92.

(375) Pate RR, Freedson PS, Sallis JF, Taylor WC, Sirard J, Trost SG et al. Compliance with physical activity guidelines: prevalence in a population of children and youth. Ann Epidemiol 2002; 12(5):303-308.

(376) van Sluijs EM, Skidmore PM, Mwanza K, Jones AP, Callaghan AM, Ekelund U et al. Physical activity and dietary behaviour in a population-based sample of British 10-year old children: the SPEEDY study (Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people). BMC Public Health 2008; 8(1):388.

(377) Trayers T, Cooper AR, Riddoch CJ, Ness AR, Fox KR, Deem R et al. Do children from an inner city British school meet the recommended levels of physical activity? Results from a cross sectional survey using objective measurements of physical activity. Arch Dis Child 2006; 91(2):175-176.

(378) Basterfield L, Adamson AJ, Parkinson KN, Maute U, Li PX, Reilly JJ et al. Surveillance of physical activity in the UK is flawed: validation of the Health Survey for England Physical Activity Questionnaire. Arch Dis Child 2008; 93(12):1054-1058.

(379) Coward WA, Wright A, Bluck LJC. Comparisons between energy intake and energy expenditure in the NDNS survey adults aged 19-64 years. 2000.
Ref Type: Unpublished Work

(380) Neilson HK, Robson PJ, Friedenreich CM, Csizmadi I. Estimating activity energy expenditure: how valid are physical activity questionnaires? Am J Clin Nutr 2008; 87(2):279-291.

(381) Saris WH, Blair SN, van Baak MA, Eaton SB, Davies PS, Di Pietro L et al. How much physical activity is enough to prevent unhealthy weight gain? Outcome of the IASO 1st Stock Conference and consensus statement. Obes Rev 2003; 4(2):101-114.

(382) The Information Centre. Statistics on Obesity, Physical Activity and Diet: England, 2006. http://www.ic.nhs.uk/pubs/obesity/opan06/file . 2006.
Ref Type: Electronic Citation

(383) Office for National Statistics. Time use survey, 2005. 2006. London, Office for National Statistics.
Ref Type: Report

(384) Stamatakis E, Ekelund U, Wareham NJ. Temporal trends in physical activity in England: The Health Survey for England 1991 to 2004. Prev Med 2007; 45(6):416-423.

(385) Stamatakis E, Ekelund U, Wareham NJ. Temporal trends in physical activity in England: The Health Survey for England 1991 to 2004. Prev Med 2007; 45(6):416-423.

(386) Samdal O, Tynjala J, Roberts C, Sallis JF, Villberg J, Wold B. Trends in vigorous physical activity and TV watching of adolescents from 1986 to 2002 in seven European Countries. Eur J Public Health 2007; 17(3):242-248.

(387) Westerterp KR, Speakman JR. Physical activity energy expenditure has not

declined since the 1980s and matches energy expenditures of wild mammals. Int J Obes (Lond) 2008; 32(8):1256-1263.

(388) Fox KR, Hillsdon M. Physical activity and obesity. Obes Rev 2007; 8 Suppl 1:115-121.

(389) Kautiainen S, Koivusilta L, Lintonen T, Virtanen SM, Rimpela A. Use of information and communication technology and prevalence of overweight and obesity among adolescents. Int J Obes (Lond) 2005; 29(8):925-933.

(390) Marshall SJ, Biddle SJ, Gorely T, Cameron N, Murdey I. Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. Int J Obes Relat Metab Disord 2004; 28(10):1238-1246.

(391) Nelson MC, Gordon-Larsen P, Adair LS, Popkin BM. Adolescent physical activity and sedentary behavior: patterning and long-term maintenance. Am J Prev Med 2005; 28(3):259-266.

(392) Davison KK, Marshall SJ, Birch LL. Cross-sectional and longitudinal associations between TV viewing and girls' body mass index, overweight status, and percentage of body fat. J Pediatr 2006; 149(1):32-37.

(393) Parsons TJ, Manor O, Power C. Television viewing and obesity: a prospective study in the 1958 British birth cohort. Eur J Clin Nutr 2008; 62(12):1355-1363.

(394) Hancox RJ, Milne BJ, Poulton R. Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. Lancet 2004; 364(9430):257-262.

(395) Hancox RJ, Poulton R. Watching television is associated with childhood obesity: but is it clinically important? Int J Obes (Lond) 2006; 30(1):171-175.

(396) Jago R, Baranowski T, Baranowski JC, Thompson D, Greaves KA. BMI from 3-6 y of age is predicted by TV viewing and physical activity, not diet. Int J Obes (Lond) 2005; 29(6):557-564.

(397) Reilly JJ, Armstrong J, Dorosty AR, Emmett PM, Ness A, Rogers I et al. Early life risk factors for obesity in childhood: cohort study. BMJ 2005; 330(7504):1357.

(398) Viner RM, Cole TJ. Television viewing in early childhood predicts adult body mass index. J Pediatr 2005; 147(4):429-435.

(399) Bryant MJ, Lucove JC, Evenson KR, Marshall S. Measurement of television viewing in children and adolescents: a systematic review. Obes Rev 2007; 8(3):197-209.

(400) Taveras EM, Field AE, Berkey CS, Rifas-Shiman SL, Frazier AL, Colditz GA et al. Longitudinal relationship between television viewing and leisure-time physical activity during adolescence. Pediatrics 2007; 119(2):e314-

e319.

(401) Borzekowski DL, Robinson TN. The 30-second effect: an experiment revealing the impact of television commercials on food preferences of preschoolers. J Am Diet Assoc 2001; 101(1):42-46.

(402) Utter J, Scragg R, Schaaf D. Associations between television viewing and consumption of commonly advertised foods among New Zealand children and young adolescents. Public Health Nutr 2006; 9(5):606-612.

(403) Matheson DM, Killen JD, Wang Y, Varady A, Robinson TN. Children's food consumption during television viewing. Am J Clin Nutr 2004; 79(6):1088-1094.

(404) Gore SA, Foster JA, DiLillo VG, Kirk K, Smith WD. Television viewing and snacking. Eat Behav 2003; 4(4):399-405.

(405) Gorely T, Marshall SJ, Biddle SJ. Couch kids: correlates of television viewing among youth. Int J Behav Med 2004; 11(3):152-163.

(406) Ekelund U, Brage S, Besson H, Sharp S, Wareham NJ. Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? Am J Clin Nutr 2008; 88(3):612-617.

(407) Demattia L, Lemont L, Meurer L. Do interventions to limit sedentary behaviours change behaviour and reduce childhood obesity? A critical review of the literature. Obes Rev 2007; 8(1):69-81.

(408) Miller WC, Koceja DM, Hamilton EJ. A meta-analysis of the past 25 years of weight loss research using diet, exercise or diet plus exercise intervention. Int J Obes Relat Metab Disord 1997; 21(10):941-947.

(409) Astrup A. How to maintain a healthy body weight. Int J Vitam Nutr Res 2006; 76(4):208-215.

(410) Shaw K, Gennat H, O'Rourke P, Del Mar C. Exercise for overweight or obesity. Cochrane Database Syst Rev 2006;(4):CD003817.

(411) Bensimhon DR, Kraus WE, Donahue MP. Obesity and physical activity: a review. Am Heart J 2006; 151(3):598-603.

(412) Atlantis E, Barnes EH, Singh MAF. Efficacy of exercise for treating overweight in children and adolescents: a systematic review. Int J Obes 2006; 30(7):1027-1040.

(413) Wing RR, Hill JO. Successful weight loss maintenance. Annu Rev Nutr 2001; 21:323-341.

(414) Fogelholm M, Kukkonen-Harjula K. Does physical activity prevent weight gain--a systematic review. Obes Rev 2000; 1(2):95-111.

(415) Molnar D, Livingstone B. Physical activity in relation to overweight and

obesity in children and adolescents. Eur J Pediatr 2000; 159 Suppl 1:S45-S55.

(416) Owens JF, Matthews KA, Wing RR, Kuller LH. Can physical activity mitigate the effects of aging in middle-aged women? Circulation 1992; 85(4):1265-1270.

(417) Haapanen N, Miilunpalo S, Pasanen M, Oja P, Vuori I. Association between leisure time physical activity and 10-year body mass change among working-aged men and women. Int J Obes Relat Metab Disord 1997; 21(4):288-296.

(418) Crawford DA, Jeffery RW, French SA. Television viewing, physical inactivity and obesity. Int J Obes Relat Metab Disord 1999; 23(4):437-440.

(419) Parker DR, Gonzalez S, Derby CA, Gans KM, Lasater TM, Carleton RA. Dietary factors in relation to weight change among men and women from two southeastern New England communities. Int J Obes Relat Metab Disord 1997; 21(2):103-109.

(420) Williamson DF, Madans J, Anda RF, Kleinman JC, Kahn HS, Byers T. Recreational physical activity and ten-year weight change in a US national cohort. Int J Obes Relat Metab Disord 1993; 17(5):279-286.

(421) Bild DE, Sholinsky P, Smith DE, Lewis CE, Hardin JM, Burke GL. Correlates and predictors of weight loss in young adults: the CARDIA study. Int J Obes Relat Metab Disord 1996; 20(1):47-55.

(422) Klesges RC, Klesges LM, Haddock CK, Eck LH. A longitudinal analysis of the impact of dietary intake and physical activity on weight change in adults. Am J Clin Nutr 1992; 55(4):818-822.

(423) Kahn HS, Tatham LM, Rodriguez C, Calle EE, Thun MJ, Heath CW, Jr. Stable behaviors associated with adults' 10-year change in body mass index and likelihood of gain at the waist. Am J Public Health 1997; 87(5):747-754.

(424) Taylor CB, Jatulis DE, Winkleby MA, Rockhill BJ, Kraemer HC. Effects of life-style on body mass index change. Epidemiology 1994; 5(6):599-603.

(425) Coakley EH, Rimm EB, Colditz G, Kawachi I, Willett W. Predictors of weight change in men: results from the Health Professionals Follow-up Study. Int J Obes Relat Metab Disord 1998; 22(2):89-96.

(426) Guo SS, Zeller C, Chumlea WC, Siervogel RM. Aging, body composition, and lifestyle: the Fels Longitudinal Study. Am J Clin Nutr 1999; 70(3):405-411.

(427) Fogelholm M, Kujala U, Kaprio J, Sarna S. Predictors of weight change in middle-aged and old men. Obes Res 2000; 8(5):367-373.

(428) Rissanen AM, Heliovaara M, Knekt P, Reunanen A, Aromaa A. Determinants of weight gain and overweight in adult Finns. Eur J Clin Nutr

1991; 45(9):419-430.

(429) Barefoot JC, Heitmann BL, Helms MJ, Williams RB, Surwit RS, Siegler IC. Symptoms of depression and changes in body weight from adolescence to mid-life. Int J Obes Relat Metab Disord 1998; 22(7):688-694.

(430) Heitmann BL, Kaprio J, Harris JR, Rissanen A, Korkeila M, Koskenvuo M. Are genetic determinants of weight gain modified by leisure-time physical activity? A prospective study of Finnish twins. Am J Clin Nutr 1997; 66(3):672-678.

(431) French SA, Jeffery RW, Murray D. Is dieting good for you?: Prevalence, duration and associated weight and behaviour changes for specific weight loss strategies over four years in US adults. Int J Obes Relat Metab Disord 1999; 23(3):320-327.

(432) Bell AC, Ge K, Popkin BM. Weight gain and its predictors in Chinese adults. Int J Obes Relat Metab Disord 2001; 25(7):1079-1086.

(433) Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA 2003; 289(14):1785-1791.

(434) Koh-Banerjee P, Chu NF, Spiegelman D, Rosner B, Colditz G, Willett W et al. Prospective study of the association of changes in dietary intake, physical activity, alcohol consumption, and smoking with 9-y gain in waist circumference among 16 587 US men. Am J Clin Nutr 2003; 78(4):719-727.

(435) Macdonald HM, New SA, Campbell MK, Reid DM. Longitudinal changes in weight in perimenopausal and early postmenopausal women: effects of dietary energy intake, energy expenditure, dietary calcium intake and hormone replacement therapy. Int J Obes Relat Metab Disord 2003; 27(6):669-676.

(436) Schmitz KH, Jacobs DR, Jr., Leon AS, Schreiner PJ, Sternfeld B. Physical activity and body weight: associations over ten years in the CARDIA study. Coronary Artery Risk Development in Young Adults. Int J Obes Relat Metab Disord 2000; 24(11):1475-1487.

(437) Drøyvold WB, Holmen J, Midthjell K, Lydersen S. BMI change and leisure time physical activity (LTPA): an 11-y follow-up study in apparently healthy men aged 20-69 y with normal weight at baseline. Int J Obes Relat Metab Disord 2004; 28(3):410-417.

(438) Wenche DB, Holmen J, Kruger O, Midthjell K. Leisure time physical activity and change in body mass index: an 11-year follow-up study of 9357 normal weight health women 20-49 years old. J Womens Health (Larchmt) 2004; 13(1):55-62.

(439) Sherwood NE, Jeffery RW, French SA, Hannan PJ, Murray DM. Predictors of weight gain in the Pound of Prevention study. Int J Obes Relat Metab

Disord 2000; 24(4):395-403.

(440) Wagner A, Simon C, Ducimetiere P, Montaye M, Bongard V, Yarnell J et al. Leisure-time physical activity and regular walking or cycling to work are associated with adiposity and 5 y weight gain in middle-aged men: the PRIME Study. Int J Obes Relat Metab Disord 2001; 25(7):940-948.

(441) Ball K, Mishra G, Crawford D. Which aspects of socioeconomic status are related to obesity among men and women? Int J Obes Relat Metab Disord 2002; 26(4):559-565.

(442) Rainwater DL, Mitchell BD, Comuzzie AG, VandeBerg JL, Stern MP, Maccluer JW. Association among 5-year changes in weight, physical activity, and cardiovascular disease risk factors in Mexican Americans. Am J Epidemiol 2000; 152(10):974-982.

(443) Petersen L, Schnohr P, Sorensen TI. Longitudinal study of the long-term relation between physical activity and obesity in adults. Int J Obes Relat Metab Disord 2004; 28(1):105-112.

(444) Wilsgaard T, Jacobsen BK, Arnesen E. Determining Lifestyle Correlates of Body Mass Index using Multilevel Analyses: The Tromso Study, 1979-2001. Am J Epidemiol 2005; 162(12):1179-1188.

(445) Waller K, Kaprio J, Kujala UM. Associations between long-term physical activity, waist circumference and weight gain: a 30-year longitudinal twin study. Int J Obes (Lond) 2008; 32(2):353-361.

(446) Gordon-Larsen P, Hou N, Sidney S, Sternfeld B, Lewis CE, Jacobs DR, Jr. et al. Fifteen-year longitudinal trends in walking patterns and their impact on weight change. Am J Clin Nutr 2009; 89(1):19-26.

(447) Klesges RC, Klesges LM, Eck LH, Shelton ML. A longitudinal analysis of accelerated weight gain in preschool children. Pediatrics 1995; 95(1):126-130.

(448) Maffeis C, Talamini G, Tato L. Influence of diet, physical activity and parents' obesity on children's adiposity: a four-year longitudinal study. Int J Obes Relat Metab Disord 1998; 22(8):758-764.

(449) Tammelin T, Laitinen J, Nayha S. Change in the level of physical activity from adolescence into adulthood and obesity at the age of 31 years. Int J Obes Relat Metab Disord 2004; 28(6):775-782.

(450) Bogaert N, Steinbeck KS, Baur LA, Brock K, Bermingham MA. Food, activity and family--environmental vs biochemical predictors of weight gain in children. Eur J Clin Nutr 2003; 57(10):1242-1249.

(451) Davison KK, Birch LL. Child and parent characteristics as predictors of change in girls' body mass index. Int J Obes Relat Metab Disord 2001; 25(12):1834-1842.

(452) Francis LA, Lee Y, Birch LL. Parental weight status and girls' television viewing, snacking, and body mass indexes. Obes Res 2003; 11(1):143-151.

(453) Kimm SY, Barton BA, Obarzanek E, McMahon RP, Sabry ZI, Waclawiw MA et al. Racial divergence in adiposity during adolescence: The NHLBI Growth and Health Study. Pediatrics 2001; 107(3):E34.

(454) Berkey CS, Rockett HR, Field AE, Gillman MW, Frazier AL, Camargo CA, Jr. et al. Activity, dietary intake, and weight changes in a longitudinal study of preadolescent and adolescent boys and girls. Pediatrics 2000; 105(4):E56.

(455) Berkey CS, Rockett HRH, Gillman MW, Colditz GA. One-Year Changes in Activity and in Inactivity Among 10- to 15-Year-Old Boys and Girls: Relationship to Change in Body Mass Index. Pediatrics 2003; 111(4):836-843.

(456) Horn OK, Paradis G, Potvin L, Macaulay AC, Desrosiers S. Correlates and predictors of adiposity among Mohawk children. Prev Med 2001; 33(4):274-281.

(457) O'loughlin J, Gray-Donald K, Paradis G, Meshefedjian G. One- and two-year predictors of excess weight gain among elementary schoolchildren in multiethnic, low-income, inner-city neighborhoods. Am J Epidemiol 2000; 152(8):739-746.

(458) Proctor MH, Moore LL, Gao D, Cupples LA, Bradlee ML, Hood MY et al. Television viewing and change in body fat from preschool to early adolescence: The Framingham Children's Study. Int J Obes Relat Metab Disord 2003; 27(7):827-833.

(459) Must A, Tybor DJ. Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. Int J Obes (Lond) 2005; 29 Suppl 2:S84-S96.

(460) Kimm SY, Glynn NW, Obarzanek E, Kriska AM, Daniels SR, Barton BA et al. Relation between the changes in physical activity and body-mass index during adolescence: a multicentre longitudinal study. Lancet 2005; 366(9482):301-307.

(461) Mundt CA, Baxter-Jones AD, Whiting SJ, Bailey DA, Faulkner RA, Mirwald RL. Relationships of activity and sugar drink intake on fat mass development in youths. Med Sci Sports Exerc 2006; 38(7):1245-1254.

(462) Wardle J, Brodersen NH, Boniface D. School-based physical activity and changes in adiposity. Int J Obes 2007.

(463) Must A, Bandini LG, Tybor DJ, Phillips SM, Naumova EN, Dietz WH. Activity, inactivity, and screen time in relation to weight and fatness over adolescence in girls. Obesity (Silver Spring) 2007; 15(7):1774-1781.

(464) Magarey AM, Daniels LA, Boulton TJ, Cockington RA. Predicting obesity in early adulthood from childhood and parental obesity. Int J Obes Relat

Metab Disord 2003; 27(4):505-513.

(465) Boreham C, Robson PJ, Gallagher AM, Cran GW, Savage JM, Murray LJ. Tracking of physical activity, fitness, body composition and diet from adolescence to young adulthood: The Young Hearts Project, Northern Ireland. Int J Behav Nutr Phys Act 2004; 1(1):14.

(466) Pietilainen KH, Kaprio J, Borg P, Plasqui G, Yki-Jarvinen H, Kujala UM et al. Physical Inactivity and Obesity: A Vicious Circle. Obesity (Silver Spring) 2008; 16(2):409-414.

(467) Kvaavik E, Tell GS, Klepp KI. Predictors and tracking of body mass index from adolescence into adulthood: follow-up of 18 to 20 years in the Oslo Youth Study. Arch Pediatr Adolesc Med 2003; 157(12):1212-1218.

(468) Parsons TJ, Manor O, Power C. Physical activity and change in body mass index from adolescence to mid-adulthood in the 1958 British cohort. Int J Epidemiol 2006; 35(1):197-204.

(469) Twisk JW, Kemper HC, van Mechelen W. Tracking of activity and fitness and the relationship with cardiovascular disease risk factors. Med Sci Sports Exerc 2000; 32(8):1455-1461.

(470) Yang X, Telama R, Viikari J, Raitakari OT. Risk of obesity in relation to physical activity tracking from youth to adulthood. Med Sci Sports Exerc 2006; 38(5):919-925.

(471) Yang X, Telama R, Leskinen E, Mansikkaniemi K, Viikari J, Raitakari OT. Testing a model of physical activity and obesity tracking from youth to adulthood: the cardiovascular risk in young Finns study. Int J Obes (Lond) 2007; 31(3):521-527.

(472) Wells JC, Coward WA, Cole TJ, Davies PS. The contribution of fat and fat-free tissue to body mass index in contemporary children and the reference child. Int J Obes Relat Metab Disord 2002; 26(10):1323-1328.

(473) Westerterp KR, Goran MI. Relationship between physical activity related energy expenditure and body composition: a gender difference. Int J Obes Relat Metab Disord 1997; 21(3):184-188.

(474) Hemmingsson E, Ekelund U. Is the association between physical activity and body mass index obesity dependent? Int J Obes (Lond) 2007; 31(4):663-668.

(475) Abbott RA, Davies PS. Habitual physical activity and physical activity intensity: their relation to body composition in 5.0-10.5-y-old children. Eur J Clin Nutr 2004; 58(2):285-291.

(476) Ekelund U, Aman J, Yngve A, Renman C, Westerterp K, Sjostrom M. Physical activity but not energy expenditure is reduced in obese adolescents: a case-control study. Am J Clin Nutr 2002; 76(5):935-941.

(477) Ball EJ, O'Connor J, Abbott R, Steinbeck KS, Davies PS, Wishart C et al. Total energy expenditure, body fatness, and physical activity in children aged 6-9 y. Am J Clin Nutr 2001; 74(4):524-528.

(478) Davies PS, Gregory J, White A. Physical activity and body fatness in pre-school children. Int J Obes Relat Metab Disord 1995; 19(1):6-10.

(479) DeLany JP, Bray GA, Harsha DW, Volaufova J. Energy expenditure in preadolescent African American and white boys and girls: the Baton Rouge Children's Study. Am J Clin Nutr 2002; 75(4):705-713.

(480) Rennie KL, Livingstone MB, Wells JC, McGloin A, Coward WA, Prentice AM et al. Association of physical activity with body-composition indexes in children aged 6-8 y at varied risk of obesity. Am J Clin Nutr 2005; 82(1):13-20.

(481) Tennefors C, Coward WA, Hernell O, Wright A, Forsum E. Total energy expenditure and physical activity level in healthy young Swedish children 9 or 14 months of age. Eur J Clin Nutr 2003; 57(5):647-653.

(482) Ortega FB, Ruiz JR, Sjostrom M. Physical activity, overweight and central adiposity in Swedish children and adolescents: the European Youth Heart Study. Int J Behav Nutr Phys Act 2007; 4:61.

(483) Bandini LG, Schoeller DA, Dietz WH. Energy expenditure in obese and nonobese adolescents. Pediatr Res 1990; 27(2):198-203.

(484) Delany JP, Harsha DW, Kime JC, Kumler J, Melancon L, Bray GA. Energy expenditure in lean and obese prepubertal children. Obes Res 1995; 3 Suppl 1:67-72.

(485) DeLany JP, Bray GA, Harsha DW, Volaufova J. Energy expenditure in African American and white boys and girls in a 2-y follow-up of the Baton Rouge Children's Study. Am J Clin Nutr 2004; 79(2):268-273.

(486) Goran MI, Carpenter WH, McGloin A, Johnson R, Hardin JM, Weinsier RL. Energy expenditure in children of lean and obese parents. Am J Physiol 1995; 268(5 Pt 1):E917-E924.

(487) Goran MI. Energy expenditure, body composition, and disease risk in children and adolescents. Proc Nutr Soc 1997; 56(1B):195-209.

(488) Maffeis C, Pinelli L, Zaffanello M, Schena F, Iacumin P, Schutz Y. Daily energy expenditure in free-living conditions in obese and non-obese children: comparison of doubly labelled water (2H2(18)O) method and heart-rate monitoring. Int J Obes Relat Metab Disord 1995; 19(9):671-677.

(489) Maffeis C, Zaffanello M, Pinelli L, Schutz Y. Total energy expenditure and patterns of activity in 8-10-year-old obese and nonobese children. J Pediatr Gastroenterol Nutr 1996; 23(3):256-261.

(490) Treuth MS, Figueroa-Colon R, Hunter GR, Weinsier RL, Butte NF, Goran

MI. Energy expenditure and physical fitness in overweight vs non-overweight prepubertal girls. Int J Obes Relat Metab Disord 1998; 22(5):440-447.

(491) Rowlands AV, Eston RG, Ingledew DK. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. J Appl Physiol 1999; 86(4):1428-1435.

(492) Mitchell JA, Mattocks C, Ness AR, Leary SD, Pate RR, Dowda M et al. Sedentary Behavior and Obesity in a Large Cohort of Children. Obesity (Silver Spring) 2009.

(493) Stevens J, Murray DM, Baggett CD, Elder JP, Lohman TG, Lytle LA et al. Objectively Assessed Associations between Physical Activity and Body Composition in Middle-School Girls: The Trial of Activity for Adolescent Girls. Am J Epidemiol 2007; 166(11):1298-1305.

(494) Ekelund U, Sardinha LB, Anderssen SA, Harro M, Franks PW, Brage S et al. Associations between objectively assessed physical activity and indicators of body fatness in 9- to 10-y-old European children: a population-based study from 4 distinct regions in Europe (the European Youth Heart Study). Am J Clin Nutr 2004; 80(3):584-590.

(495) Janz KF, Levy SM, Burns TL, Torner JC, Willing MC, Warren JJ. Fatness, physical activity, and television viewing in children during the adiposity rebound period: the Iowa Bone Development Study. Prev Med 2002; 35(6):563-571.

(496) Gutin B, Yin Z, Humphries MC, Barbeau P. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. Am J Clin Nutr 2005; 81(4):746-750.

(497) Lohman TG, Ring K, Schmitz KH, Treuth MS, Loftin M, Yang S et al. Associations of body size and composition with physical activity in adolescent girls. Med Sci Sports Exerc 2006; 38(6):1175-1181.

(498) Metallinos-Katsaras E, Freedson PS, Fulton JE, Sherry B. The Association Between an Objective Measure of Physical Activity and Weight Status in Preschoolers. Obesity Res 2007; 15(3):686-694.

(499) Ruiz JR, Rizzo NS, Hurtig-Wennlof A, Ortega FB, Warnberg J, Sjostrom M. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. Am J Clin Nutr 2006; 84(2):299-303.

(500) Treuth MS, Catellier DJ, Schmitz KH, Pate RR, Elder JP, McMurray RG et al. Weekend and Weekday Patterns of Physical Activity in Overweight and Normal-weight Adolescent Girls. Obesity Res 2007; 15(7):1782-1788.

(501) Ness AR, Leary SD, Mattocks C, Blair SN, Reilly JJ, Wells J et al. Objectively Measured Physical Activity and Fat Mass in a Large Cohort of

Children. PLoS Medicine 2007; 4(3):e97.

(502) Ekelund U, Brage S, Froberg K, Harro M, Anderssen SA, Sardinha LB et al. TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study. PLoS Med 2006; 3(12):e488.

(503) Treuth MS, Hou N, Young DR, Maynard LM. Accelerometry-measured activity or sedentary time and overweight in rural boys and girls. Obes Res 2005; 13(9):1606-1614.

(504) Hussey J, Bell C, Bennett K, O'Dwyer J, Gormley J. Relationship between the intensity of physical activity, inactivity, cardiorespiratory fitness and body composition in 7-10-year-old Dublin children. Br J Sports Med 2007; 41(5):311-316.

(505) Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S et al. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). Lancet 2006; 368(9532):299-304.

(506) Saelens BE, Seeley RJ, van Schaick K, Donnelly LF, O'Brien KJ. Visceral abdominal fat is correlated with whole-body fat and physical activity among 8-y-old children at risk of obesity. Am J Clin Nutr 2007; 85(1):46-53.

(507) Page A, Cooper AR, Stamatakis E, Foster LJ, Crowne EC, Sabin M et al. Physical activity patterns in nonobese and obese children assessed using minute-by-minute accelerometry. Int J Obes (Lond) 2005; 29(9):1070-1076.

(508) Hughes AR, Henderson A, Ortiz-Rodriguez V, Artinou ML, Reilly JJ. Habitual physical activity and sedentary behaviour in a clinical sample of obese children. Int J Obes (Lond) 2006; 30(10):1494-1500.

(509) Butte NF, Puyau MR, Adolph AL, Vohra FA, Zakeri I. Physical activity in nonoverweight and overweight Hispanic children and adolescents. Med Sci Sports Exerc 2007; 39(8):1257-1266.

(510) Trost SG, Kerr LM, Ward DS, Pate RR. Physical activity and determinants of physical activity in obese and non-obese children. Int J Obes Relat Metab Disord 2001; 25(6):822-829.

(511) Prentice AM, Black AE, Coward WA, Davies HL, Goldberg GR, Murgatroyd PR et al. High levels of energy expenditure in obese women. Br Med J (Clin Res Ed) 1986; 292(6526):983-987.

(512) Spadano JL, Bandini LG, Must A, Dallal GE, Dietz WH. Longitudinal changes in energy expenditure in girls from late childhood through midadolescence. Am J Clin Nutr 2005; 81(5):1102-1109.

(513) Spadano JL, Must A, Bandini LG, Dallal GE, Dietz WH. Energy cost of physical activities in 12-y-old girls: MET values and the influence of body weight. Int J Obes Relat Metab Disord 2003; 27(12):1528-1533.

(514) Tataranni PA, Harper IT, Snitker S, Del Parigi A, Vozarova B, Bunt J et al. Body weight gain in free-living Pima Indians: effect of energy intake vs expenditure. Int J Obes Relat Metab Disord 2003; 27(12):1578-1583.

(515) Ekelund U, Brage S, Franks PW, Hennings S, Emms S, Wong MY et al. Physical activity energy expenditure predicts changes in body composition in middle-aged healthy whites: effect modification by age. Am J Clin Nutr 2005; 81(5):964-969.

(516) Ekelund U, Sarnblad S, Brage S, Ryberg J, Wareham NJ, Aman J. Does physical activity equally predict gain in fat mass among obese and nonobese young adults? Int J Obes (Lond) 2007; 31(1):65-71.

(517) Luke A, Dugas LR, Ebersole K, Durazo-Arvizu RA, Cao G, Schoeller DA et al. Energy expenditure does not predict weight change in either Nigerian or African American women. Am J Clin Nutr 2009; 89(1):169-176.

(518) Molnar D, Livingstone B. Physical activity in relation to overweight and obesity in children and adolescents. Eur J Pediatr 2000; 159 Suppl 1:S45-S55.

(519) Roberts SB, Savage J, Coward WA, Chew B, Lucas A. Energy expenditure and intake in infants born to lean and overweight mothers. N Engl J Med 1988; 318(8):461-466.

(520) Davies PS, Day JM, Lucas A. Energy expenditure in early infancy and later body fatness. Int J Obes 1991; 15(11):727-731.

(521) Goran MI, Shewchuk R, Gower BA, Nagy TR, Carpenter WH, Johnson RK. Longitudinal changes in fatness in white children: no effect of childhood energy expenditure. Am J Clin Nutr 1998; 67(2):309-316.

(522) Moore LL, Gao D, Bradlee ML, Cupples LA, Sundarajan-Ramamurti A, Proctor MH et al. Does early physical activity predict body fat change throughout childhood? Prev Med 2003; 37(1):10-17.

(523) Figueroa-Colon R, Arani RB, Goran MI, Weinsier RL. Paternal body fat is a longitudinal predictor of changes in body fat in premenarcheal girls. Am J Clin Nutr 2000; 71(3):829-834.

(524) Treuth MS, Butte NF, Sorkin JD. Predictors of body fat gain in nonobese girls with a familial predisposition to obesity. Am J Clin Nutr 2003; 78(6):1212-1218.

(525) Johnson MS, Figueroa-Colon R, Herd SL, Fields DA, Sun M, Hunter GR et al. Aerobic Fitness, Not Energy Expenditure, Influences Subsequent Increase in Adiposity in Black and White Children. Pediatrics 2000; 106(4):e50.

(526) Wells JC, Ritz P. Physical activity at 9-12 months and fatness at 2 years of age. Am J Hum Biol 2001; 13(3):384-389.

(527) Salbe AD, Weyer C, Harper I, Lindsay RS, Ravussin E, Tataranni PA. Assessing Risk Factors for Obesity Between Childhood and Adolescence: II. Energy Metabolism and Physical Activity. Pediatrics 2002; 110(2):307-314.

(528) Bandini LG, Must A, Phillips SM, Naumova EN, Dietz WH. Relation of body mass index and body fatness to energy expenditure: longitudinal changes from preadolescence through adolescence. Am J Clin Nutr 2004; 80(5):1262-1269.

(529) Stevens J, Suchindran C, Ring K, Baggett CD, Jobe JB, Story M et al. Physical Activity as a Predictor of Body Composition in American Indian Children. Obesity Res 2004; 12(12):1974-1980.

(530) Metcalf BS, Voss LD, Hosking J, Jeffery AN, Wilkin TJ. Physical activity at the government-recommended level and obesity-related health outcomes: a longitudinal study (Early Bird 37). Arch Dis Child 2008; 93(9):772-777.

(531) Janz KF, Burns TL, Levy SM. Tracking of activity and sedentary behaviors in childhood: the Iowa Bone Development Study. Am J Prev Med 2005; 29(3):171-178.

(532) Butte NF, Cai G, Cole SA, Wilson TA, Fisher JO, Zakeri IF et al. Metabolic and behavioral predictors of weight gain in Hispanic children: the Viva la Familia Study. Am J Clin Nutr 2007; 85(6):1478-1485.

(533) Styne DM. Obesity in childhood: what's activity got to do with it? Am J Clin Nutr 2005; 81(2):337-338.

(534) Dietz WH. Does energy expenditure affect changes in body fat in children? Am J Clin Nutr 1998; 67(2):190-191.

(535) Tremblay A, Simoneau JA, Bouchard C. Impact of exercise intensity on body fatness and skeletal muscle metabolism. Metabolism 1994; 43(7):814-818.

(536) Yoshioka M, Doucet E, St Pierre S, Almeras N, Richard D, Labrie A et al. Impact of high-intensity exercise on energy expenditure, lipid oxidation and body fatness. Int J Obes Relat Metab Disord 2001; 25(3):332-339.

(537) Grediagin A, Cody M, Rupp J, Benardot D, Shern R. Exercise intensity does not effect body composition change in untrained, moderately overfat women. J Am Diet Assoc 1995; 95(6):661-665.

(538) Lemura LM, Maziekas MT. Factors that alter body fat, body mass, and fat-free mass in pediatric obesity. Med Sci Sports Exerc 2002; 34(3):487-496.

(539) Hardeman W, Griffin S, Johnston M, Kinmonth AL, Wareham NJ. Interventions to prevent weight gain: a systematic review of psychological models and behaviour change methods. Int J Obes Relat Metab Disord 2000; 24(2):131-143.

(540) Fitzgibbon ML, Stolley MR, Kirschenbaum DS. An obesity prevention pilot

program in African-American mothers and daughters. J Nutr Educ 1995; 27:93-97.

(541) Forster JL, Jeffery RW, Schmid TL, Kramer FM. Preventing weight gain in adults: a pound of prevention. Health Psychol 1988; 7(6):515-525.

(542) Jeffery RW, French SA. Preventing weight gain in adults: design, methods and one year results from the Pound of Prevention study. Int J Obes Relat Metab Disord 1997; 21(6):457-464.

(543) Sherwood NE, Morton N, Jeffery RW, French SA, Neumark-Sztainer D, Falkner NH. Consumer preferences in format and type of community-based weight control programs. Am J Health Promot 1998; 13(1):12-18.

(544) Simonetti D'Arca A, Tarsitani G, Cairella M, Siani V, De Filippis S, Mancinelli S et al. Prevention of obesity in elementary and nursery school children. Public Health 1986; 100(3):166-173.

(545) Caballero B. Obesity prevention in American Indian schoolchildren: Pathways. Am J Clin Nutr 1999; 69(4):745S-7746.

(546) Cairella G, Romagnoli F, Cantarelli P, Valentini P, Tarsitani G. School oriented intervention on dietary education: Results of phase 1. Int J Obes Relat Metab Disord 1998; 22(Suppl):S254 (Abstract).

(547) Davis S, Gomez Y, Lambert L, Skipper B. Primary prevention of obesity in American Indian children. In: Williams CL, Kimm SYS, editors. Pevention and treatment of childhood obesity. New York: New York Academy of Sciences, 1993: 167-180.

(548) Donnelly JE, Jacobsen DJ, Whatley JE, Hill JO, Swift LL, Cherrington A et al. Nutrition and physical activity program to attenuate obesity and promote physical and metabolic fitness in elementary school children. Obes Res 1996; 4(3):229-243.

(549) Gittelsohn J, Evans M, Helitzer D, Anliker J, Story M, Metcalfe L et al. Formative research in a school-based obesity prevention program for Native American school children (Pathways). Health Educ Res 1998; 13(2):251-265.

(550) Stolley MR, Fitzgibbon ML. Effects of an obesity prevention program on the eating behavior of African American mothers and daughters. Health Educ Behav 1997; 24(2):152-164.

(551) Littrell KH, Hilligoss NM, Kirshner CD, Petty RG, Johnson CG. The effects of an educational intervention on antipsychotic-induced weight gain. J Nurs Scholarsh 2003; 35(3):237-241.

(552) Simkin-Silverman LR, Wing RR, Boraz MA, Kuller LH. Lifestyle intervention can prevent weight gain during menopause: results from a 5-year randomized clinical trial. Ann Behav Med 2003; 26(3):212-220.

(553) Muto T, Yamauchi K. Evaluation of a multicomponent workplace health promotion program conducted in Japan for improving employees' cardiovascular disease risk factors. Prev Med 2001; 33(6):571-577.

(554) Proper KI, Hildebrandt VH, van der Beek AJ, Twisk JW, van Mechelen W. Effect of individual counseling on physical activity fitness and health: a randomized controlled trial in a workplace setting. Am J Prev Med 2003; 24(3):218-226.

(555) Burke V, Giangiulio N, Gillam HF, Beilin LJ, Houghton S. Physical activity and nutrition programs for couples: a randomized controlled trial. J Clin Epidemiol 2003; 56(5):421-432.

(556) Polley BA, Wing RR, Sims CJ. Randomized controlled trial to prevent excessive weight gain in pregnant women. Int J Obes Relat Metab Disord 2002; 26(11):1494-1502.

(557) Kain J, Uauy R, Albala, Vio F, Cerda R, Leyton B. School-based obesity prevention in Chilean primary school children: methodology and evaluation of a controlled study. Int J Obes Relat Metab Disord 2004; 28(4):483-493.

(558) McMurray RG, Harrell JS, Bangdiwala SI, Bradley CB, Deng S, Levine A. A school-based intervention can reduce body fat and blood pressure in young adolescents. J Adolesc Health 2002; 31(2):125-132.

(559) Sallis JF, McKenzie TL, Conway TL, Elder JP, Prochaska JJ, Brown M et al. Environmental interventions for eating and physical activity: a randomized controlled trial in middle schools. Am J Prev Med 2003; 24(3):209-217.

(560) Baranowski T, Baranowski JC, Cullen KW, Thompson DI, Nicklas T, Zakeri IE et al. The Fun, Food, and Fitness Project (FFFP): the Baylor GEMS pilot study. Ethn Dis 2003; 13(1 Suppl 1):S30-S39.

(561) Caballero B, Clay T, Davis SM, Ethelbah B, Rock BH, Lohman T et al. Pathways: a school-based, randomized controlled trial for the prevention of obesity in American Indian schoolchildren. Am J Clin Nutr 2003; 78(5):1030-1038.

(562) Dennison BA, Russo TJ, Burdick PA, Jenkins PL. An intervention to reduce television viewing by preschool children. Arch Pediatr Adolesc Med 2004; 158(2):170-176.

(563) Neumark-Sztainer D, Story M, Hannan PJ, Rex J. New Moves: a school-based obesity prevention program for adolescent girls. Prev Med 2003; 37(1):41-51.

(564) Pangrazi RP, Beighle A, Vehige T, Vack C. Impact of Promoting Lifestyle Activity for Youth (PLAY) on children's physical activity. J Sch Health 2003; 73(8):317-321.

(565) Robinson TN, Killen JD, Kraemer HC, Wilson DM, Matheson DM, Haskell

WL et al. Dance and reducing television viewing to prevent weight gain in African-American girls: the Stanford GEMS pilot study. Ethn Dis 2003; 13(1 Suppl 1):S65-S77.

(566) Sahota P, Rudolf MC, Dixey R, Hill AJ, Barth JH, Cade J. Randomised controlled trial of primary school based intervention to reduce risk factors for obesity. BMJ 2001; 323(7320):1029-1032.

(567) Warren JM, Henry CJ, Lightowler HJ, Bradshaw SM, Perwaiz S. Evaluation of a pilot school programme aimed at the prevention of obesity in children. Health Promot Int 2003; 18(4):287-296.

(568) Reilly JJ, Kelly L, Montgomery C, Williamson A, Fisher A, McColl JH et al. Physical activity to prevent obesity in young children: cluster randomised controlled trial. BMJ 2006; 333(7577):1041.

(569) Simon C, Schweitzer B, Oujaa M, Wagner A, Arveiler D, Triby E et al. Successful overweight prevention in adolescents by increasing physical activity: a 4-year randomized controlled intervention. Int J Obes (Lond) 2008; 32(10):1489-1498.

(570) Walker A, Maher J, Coulthard M, Goddard E, Thomas M. Living in Britain: Results from the 2000/01 General Household Survey. 2001. London, The Stationery Office.
Ref Type: Report

(571) Elia M. Changing concepts of nutrient requirements in disease: implications for artificial nutritional support. Lancet 1995; 345(8960):1279-1284.

(572) Eddy TP, Nicholson AL, Wheeler EF. Energy expenditures and dietary intakes in cerebral palsy. Dev Med Child Neurol 1965; 7(4):377-386.

(573) Elia M. Tissue distribution and energetics in weigh loss and undernutrition. In: Tucker HN, Kinney JM, editors. Physiology,Stress and Malnutrition: Functional Correlates and Nutritional Intervention. New York: Lipcott-Raven, 1997.

(574) Elia M. Organ and tissue contribution to metabolic rate. Energy Metabolism: Tissue Determinants and Cellular Corollaries. New York: Raven Press, 1992: 61-79.

(575) Casper RC, Schoeller DA, Kushner R, Hnilicka J, Gold ST. Total daily energy expenditure and activity level in anorexia nervosa. Am J Clin Nutr 1991; 53(5):1143-1150.

(576) Marken Lichtenbelt WD, Heidendal GA, Westerterp KR. Energy expenditure and physical activity in relation to bone mineral density in women with anorexia nervosa. Eur J Clin Nutr 1997; 51(12):826-830.

(577) Bessey PQ, Wilmore DW. The burned patient. Nutrition and Metabolism in Patient Care. London: W.B. Saunders, 1988: 672-700.

(578) Elia M. Hunger disease: metabolic response to starvation, injury and sepsis. Clin Nutr 2000; 19(6):379-386.

(579) Magoffin A, Allen JR, McCauley J, Gruca MA, Peat J, Van Asperen P et al. Longitudinal analysis of resting energy expenditure in patients with cystic fibrosis. J Pediatr 2008; 152(5):703-708.

(580) Tomezsko JL, Stallings VA, Kawchak DA, Goin JE, Diamond G, Scanlin TF. Energy expenditure and genotype of children with cystic fibrosis. Pediatr Res 1994; 35(4 Pt 1):451-460.

(581) Kuip M, Hoos MB, Forget PP, Westerterp KR, Gemke RJBJ, Meer Kd. Energy expenditure in infants with congenital heart disease, including a meta-analysis. Acta Paediatrica 2003; 92(8):921-927.

(582) Jebb SA, Prentice AM, Goldberg GR, Murgatroyd PR, Black AE, Coward WA. Changes in macronutrient balance during over- and underfeeding assessed by 12-d continuous whole-body calorimetry. Am J Clin Nutr 1996; 64(3):259-266.

(583) Bullough RC, Gillette CA, Harris MA, Melby CL. Interaction of acute changes in exercise energy expenditure and energy intake on resting metabolic rate. Am J Clin Nutr 1995; 61(3):473-481.

(584) Tarasuk V, Beaton GH. The nature and individuality of within-subject variation in energy intake. Am J Clin Nutr 1991; 54(3):464-470.

(585) Wynne K, Stanley S, McGowan B, Bloom S. Appetite control. J Endocrinol 2005; 184(2):291-318.

(586) Druce M, Bloom SR. The regulation of appetite. Arch Dis Child 2006; 91(2):183-187.

(587) Major GC, Doucet E, Trayhurn P, Astrup A, Tremblay A. Clinical significance of adaptive thermogenesis. Int J Obes (Lond) 2007; 31(2):204-212.

(588) Leibel RL, Rosenbaum M, Hirsch J. Changes in Energy Expenditure Resulting from Altered Body Weight. N Engl J Med 1995; 332(10):621-628.

(589) Weyer C, Walford RL, Harper IT, Milner M, MacCallum T, Tataranni PA et al. Energy metabolism after 2 y of energy restriction: the Biosphere 2 experiment. Am J Clin Nutr 2000; 72(4):946-953.

(590) Martin CK, Heilbronn LK, de Jonge L, Delany JP, Volaufova J, Anton SD et al. Effect of calorie restriction on resting metabolic rate and spontaneous physical activity. Obesity (Silver Spring) 2007; 15(12):2964-2973.

(591) Dulloo AG. Suppressed thermogenesis as a cause for resistance to slimming and obesity rebound: adaptation or illusion? Int J Obes (Lond) 2007; 31(2):201-203.

(592) Diaz EO, Prentice AM, Goldberg GR, Murgatroyd PR, Coward WA. Metabolic response to experimental overfeeding in lean and overweight healthy volunteers. Am J Clin Nutr 1992; 56(4):641-655.

(593) Heyman MB, Young VR, Fuss P, Tsay R, Joseph L, Roberts SB. Underfeeding and body weight regulation in normal-weight young men. Am J Physiol Regul Integr Comp Physiol 1992; 263(2):R250-R257.

(594) Hill JO, Sparling PB, Shields TW, Heller PA. Effects of exercise and food restriction on body composition and metabolic rate in obese women. Am J Clin Nutr 1987; 46(4):622-630.

(595) Payne PR, Dugdale AE. A model for the prediction of energy balance and body weight. Ann Hum Biol 1977; 4(6):525-535.

(596) Rolls ET. Sensory processing in the brain related to the control of food intake. Proc Nutr Soc 2007; 66(1):96-112.

(597) Rolls ET. Understanding the mechanisms of food intake and obesity. Obes Rev 2007; 8 Suppl 1:67-72.

(598) Elia M. Fuel of the Tissues. In: Garrow JS, James WPT, Ralph A, editors. Human Nutrition and Dietetics. London: Churchill Livingstone, 2000: 37-59.

(599) Henry CJ, Rivers JP, Payne PR. Protein and energy metabolism in starvation reconsidered. Eur J Clin Nutr 1988; 42(7):543-549.

(600) Randle PJ. Metabolic fuel selection: general integration at the whole-body level. Proc Nutr Soc 1995; 54(1):317-327.

(601) Westerterp KR. Food quotient, respiratory quotient, and energy balance. Am J Clin Nutr 1993; 57(5):759S-7764.

(602) Treuth MS, Sunehag AL, Trautwein LM, Bier DM, Haymond MW, Butte NF. Metabolic adaptation to high-fat and high-carbohydrate diets in children and adolescents. Am J Clin Nutr 2003; 77(2):479-489.

(603) Smith SR, de Jonge L, Zachwieja JJ, Roy H, Nguyen T, Rood JC et al. Fat and carbohydrate balances during adaptation to a high-fat diet. Am J Clin Nutr 2000; 71(2):450-457.

(604) Roy HJ, Lovejoy JC, Keenan MJ, Bray GA, Windhauser MM, Wilson JK. Substrate oxidation and energy expenditure in athletes and nonathletes consuming isoenergetic high- and low-fat diets. Am J Clin Nutr 1998; 67(3):405-411.

(605) Schrauwen P, Marken Lichtenbelt WD, Saris WH, Westerterp KR. Changes in fat oxidation in response to a high-fat diet. Am J Clin Nutr 1997; 66(2):276-282.

(606) Hill JO, Peters JC, Reed GW, Schlundt DG, Sharp T, Greene HL. Nutrient

balance in humans: effects of diet composition. Am J Clin Nutr 1991; 54(1):10-17.

(607) Vasilaras TH, Raben A, Astrup A. Twenty-four hour energy expenditure and substrate oxidation before and after 6 months' ad libitum intake of a diet rich in simple or complex carbohydrates or a habitual diet. Int J Obes Relat Metab Disord 2001; 25(7):954-965.

(608) Davy KP, Horton T, Davy BM, Bessessen D, Hill JO. Regulation of macronutrient balance in healthy young and older men. Int J Obes Relat Metab Disord 2001; 25(10):1497-1502.

(609) Schrauwen P, Marken Lichtenbelt WD, Westerterp KR. Fat and carbohydrate balances during adaptation to a high-fat diet. Am J Clin Nutr 2000; 72(5):1239-1240.

(610) Smith SR, de Jonge L, Zachwieja JJ, Roy H, Nguyen T, Rood J et al. Concurrent physical activity increases fat oxidation during the shift to a high-fat diet. Am J Clin Nutr 2000; 72(1):131-138.

(611) Hansen KC, Zhang Z, Gomez T, Adams AK, Schoeller DA. Exercise increases the proportion of fat utilization during short-term consumption of a high-fat diet. Am J Clin Nutr 2007; 85(1):109-116.

(612) Jeukendrup AE. Modulation of carbohydrate and fat utilization by diet, exercise and environment. Biochem Soc Trans 2003; 31(Pt 6):1270-1273.

(613) Price GM, Halliday D, Pacy PJ, Quevedo MR, Millward DJ. Nitrogen homeostasis in man: influence of protein intake on the amplitude of diurnal cycling of body nitrogen. Clin Sci (Lond) 1994; 86(1):91-102.

(614) Blaak EE, Hul G, Verdich C, Stich V, Martinez A, Petersen M et al. Fat oxidation before and after a high fat load in the obese insulin-resistant state. J Clin Endocrinol Metab 2006; 91(4):1462-1469.

(615) Astrup A, Buemann B, Western P, Toubro S, Raben A, Christensen NJ. Obesity as an adaptation to a high-fat diet: evidence from a cross- sectional study. Am J Clin Nutr 1994; 59(2):350-355.

(616) Ranneries C, Bulow J, Buemann B, Christensen NJ, Madsen J, Astrup A. Fat metabolism in formerly obese women. Am J Physiol 1998; 274(1 Pt 1):E155-E161.

(617) Ravussin E, Smith SR. Increased fat intake, impaired fat oxidation, and failure of fat cell proliferation result in ectopic fat storage, insulin resistance, and type 2 diabetes mellitus. Ann N Y Acad Sci 2002; 967:363-378.

(618) Astrup A, Raben A, Buemann B, Toubro S. Fat metabolism in the predisposition to obesity. Ann N Y Acad Sci 1997; 827:417-430.

(619) Thomas CD, Peters JC, Reed GW, Abumrad NN, Sun M, Hill JO. Nutrient balance and energy expenditure during ad libitum feeding of high-fat and

high-carbohydrate diets in humans. Am J Clin Nutr 1992; 55(5):934-942.

(620) Westerterp KR, Smeets A, Lejeune MP, Wouters-Adriaens MP, Westerterp-Plantenga MS. Dietary fat oxidation as a function of body fat. Am J Clin Nutr 2008; 87(1):132-135.

(621) Hill JO, Wyatt HR, Reed GW, Peters JC. Obesity and the Environment: Where Do We Go from Here? Science 2003; 299(5608):853-855.

(622) Butte NF, Ellis KJ. Comment on "Obesity and the Environment: Where Do We Go from Here?". Science 2003; 301(5633):598b.

(623) Jebb SA. Dietary determinants of obesity. Obes Rev 2007; 8 Suppl 1:93-97.

(624) Bingham SA, Day N. Commentary: Fat and breast cancer: time to re-evaluate both methods and results? Int J Epidemiol 2006; 35(4):1022-1024.

(625) Bingham SA, Luben R, Welch A, Wareham N, Khaw KT, Day N. Are imprecise methods obscuring a relation between fat and breast cancer? Lancet 2003; 362(9379):212-214.

(626) Bingham SA, Welch AA, McTaggart A, Mulligan AA, Runswick SA, Luben R et al. Nutritional methods in the European Prospective Investigation of Cancer in Norfolk. Public Health Nutrition 2001; 4(03):847-858.

(627) Livingstone MB, Black AE. Markers of the validity of reported energy intake. J Nutr 2003; 133 Suppl 3:895S-920S.

(628) Rennie KL, Jebb SA, Wright A, Coward WA. Secular trends in under-reporting in young people. Br J Nutr 2005; 93(2):241-247.

(629) Champagne CM, Baker NB, Delany JP, Harsha DW, Bray GA. Assessment of energy intake underreporting by doubly labeled water and observations on reported nutrient intakes in children. J Am Diet Assoc 1998; 98(4):426-433.

(630) Bandini LG, Schoeller DA, Cyr HN, Dietz WH. Validity of reported energy intake in obese and nonobese adolescents. Am J Clin Nutr 1990; 52(3):421-425.

(631) Buhl KM, Gallagher D, Hoy K, Matthews DE, Heymsfield SB. Unexplained disturbance in body weight regulation: diagnostic outcome assessed by doubly labeled water and body composition analyses in obese patients reporting low energy intakes. J Am Diet Assoc 1995; 95(12):1393-1400.

(632) Goris AH, Westerterp-Plantenga MS, Westerterp KR. Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake1. Am J Clin Nutr 2000; 71(1):130-134.

(633) Lichtman SW, Pisarska K, Berman ER, Pestone M, Dowling H, Offenbacher E et al. Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. N Engl J Med 1992; 327(27):1893-1898.

(634) Williamson DF. Dietary intake and physical activity as "predictors" of weight gain in observational, prospective studies of adults. Nutr Rev 1996; 54(4 Pt 2):S101-S109.

(635) DEFRA. Household Food Consumption, Great Britain, 1974 - 2000: National Food Survey. http://www.statistics.gov.uk/StatBase/Expodata/Spreadsheets/D3802.xls . 2002. DEFRA.
Ref Type: Electronic Citation

(636) DEFRA. Family Food in 2006. 2008. London, TSO.
Ref Type: Report

(637) DEFRA. Expenditure on food eaten out: by region, 1998: Social Trends 30. http://statistics.defra.gov.uk/esg/publications/efs/default.asp . 2002. DEFRA.
Ref Type: Electronic Citation

(638) Bray GA, Popkin BM. Dietary fat intake does affect obesity! Am J Clin Nutr 1998; 68(6):1157-1173.

(639) Willett WC. Is dietary fat a major determinant of body fat? Am J Clin Nutr 1998; 67(3 Suppl):556S-562S.

(640) World Cancer Research Fund / American Institute for Cancer Research. Food, Nutrition, Physical Activity, and the Prevention of Cancer: a Global Perspective. 2007. Washington DC, AICR.
Ref Type: Report

(641) Ledikwe JH, Blanck HM, Khan LK, Serdula MK, Seymour JD, Tohill BC et al. Low-energy-density diets are associated with high diet quality in adults in the United States. J Am Diet Assoc 2006; 106(8):1172-1180.

(642) Prentice AM, Jebb SA. Fast foods, energy density and obesity: a possible mechanistic link. Obes Rev 2003; 4(4):187-194.

(643) Levine AS. Energy density of foods: building a case for food intake management. Am J Clin Nutr 2001; 73(6):999-1000.

(644) Bell EA, Rolls BJ. Energy density of foods affects energy intake across multiple levels of fat content in lean and obese women. Am J Clin Nutr 2001; 73(6):1010-1018.

(645) Leahy KE, Birch LL, Rolls BJ. Reducing the energy density of multiple meals decreases the energy intake of preschool-age children. Am J Clin Nutr 2008; 88(6):1459-1468.

(646) Stubbs RJ, Johnstone AM, O'reilly LM, Barton K, Reid C. The effect of covertly manipulating the energy density of mixed diets on ad libitum food intake in 'pseudo free-living' humans. Int J Obes Relat Metab Disord 1998; 22(10):980-987.

(647) Stubbs RJ, Whybrow S. Energy density, diet composition and palatability: influences on overall food energy intake in humans. Physiol Behav 2004; 81(5):755-764.

(648) Mazlan N, Horgan G, Stubbs RJ. Energy density and weight of food effect short-term caloric compensation in men. Physiol Behav 2006; 87(4):679-686.

(649) Bell EA, Castellanos VH, Pelkman CL, Thorwart ML, Rolls BJ. Energy density of foods affects energy intake in normal-weight women. Am J Clin Nutr 1998; 67(3):412-420.

(650) Stubbs RJ, Johnstone AM, Harbron CG, Reid C. Covert manipulation of energy density of high carbohydrate diets in 'pseudo free-living' humans. Int J Obes Relat Metab Disord 1998; 22(9):885-892.

(651) Rolls BJ, Bell EA, Castellanos VH, Chow M, Pelkman CL, Thorwart ML. Energy density but not fat content of foods affected energy intake in lean and obese women. Am J Clin Nutr 1999; 69(5):863-871.

(652) Katan MB, Grundy SM, Willett WC. Should a low-fat, high-carbohydrate diet be recommended for everyone? Beyond low-fat diets. N Engl J Med 1997; 337(8):563-566.

(653) Stubbs RJ, Mazlan N, Whybrow S. Carbohydrates, appetite and feeding behavior in humans. J Nutr 2001; 131(10):2775S-2781S.

(654) Drewnowski A, Almiron-Roig E, Marmonier C, Lluch A. Dietary energy density and body weight: is there a relationship? Nutr Rev 2004; 62(11):403-413.

(655) Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA. A prospective analysis of dietary energy density at age 5 and 7 years and fatness at 9 years among UK children. Int J Obes (Lond) 2008; 32:586-593.

(656) Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA. Energy-dense, low-fiber, high-fat dietary pattern is associated with increased fatness in childhood. Am J Clin Nutr 2008; 87(4):846-854.

(657) McCaffrey TA, Rennie KL, Kerr MA, Wallace JM, Hannon-Fletcher MP, Coward WA et al. Energy density of the diet and change in body fatness from childhood to adolescence; is there a relation? Am J Clin Nutr 2008; 87(5):1230-1237.

(658) Phillips SM, Bandini LG, Naumova EN, Cyr H, Colclough S, Dietz WH et al. Energy-dense snack food intake in adolescence: longitudinal relationship to weight and fatness. Obes Res 2004; 12(3):461-472.

(659) Iqbal SI, Helge JW, Heitmann BL. Do Energy Density and Dietary Fiber Influence Subsequent 5-Year Weight Changes in Adult Men and Women? Obesity Res 2006; 14(1):106-114.

(660) Bes-Rastrollo M, van Dam RM, Martinez-Gonzalez MA, Li TY, Sampson LL, Hu FB. Prospective study of dietary energy density and weight gain in women. Am J Clin Nutr 2008; 88(3):769-777.

(661) Savage JS, Marini M, Birch LL. Dietary energy density predicts women's weight change over 6 y. Am J Clin Nutr 2008; 88(3):677-684.

(662) Deierlein AL, Siega-Riz AM, Herring A. Dietary energy density but not glycemic load is associated with gestational weight gain. Am J Clin Nutr 2008; 88(3):693-699.

(663) Sabate J. Nut consumption and body weight. Am J Clin Nutr 2003; 78(3):647S-6650.

(664) Mattes RD, Kris-Etherton PM, Foster GD. Impact of Peanuts and Tree Nuts on Body Weight and Healthy Weight Loss in Adults. J Nutr 2008; 138(9):1741S-1745.

(665) Bes-Rastrollo M, Sabate J, Gomez-Gracia E, Alonso A, Martinez JA, Martinez-Gonzalez MA. Nut Consumption and Weight Gain in a Mediterranean Cohort: The SUN Study. Obesity Res 2007; 15(1):107-116.

(666) Alper CM, Mattes RD. Effects of chronic peanut consumption on energy balance and hedonics. Int J Obes Relat Metab Disord 2002; 26(8):1129-1137.

(667) Traoret CJ, Lokko P, Cruz AC, Oliveira CG, Costa NM, Bressan J et al. Peanut digestion and energy balance. Int J Obes (Lond) 2008; 32(2):322-328.

(668) Traoret CJ, Lokko P, Cruz AC, Oliveira CG, Costa NM, Bressan J et al. Peanut digestion and energy balance. Int J Obes (Lond) 2007.

(669) Pereira MA, Kartashov AI, Ebbeling CB, Van Horn L, Slattery ML, Jacobs DR, Jr. et al. Fast-food habits, weight gain, and insulin resistance (the CARDIA study): 15-year prospective analysis. Lancet 2005; 365(9453):36-42.

(670) Taveras EM, Berkey CS, Rifas-Shiman SL, Ludwig DS, Rockett HR, Field AE et al. Association of consumption of fried food away from home with body mass index and diet quality in older children and adolescents. Pediatrics 2005; 116(4):e518-e524.

(671) Bes-Rastrollo M, Sanchez-Villegas A, Gomez-Gracia E, Martinez JA, Pajares RM, Martinez-Gonzalez MA. Predictors of weight gain in a Mediterranean cohort: the Seguimiento Universidad de Navarra Study 1. Am J Clin Nutr 2006; 83(2):362-370.

(672) Astrup A, Grunwald GK, Melanson EL, Saris WH, Hill JO. The role of low-fat diets in body weight control: a meta-analysis of ad libitum dietary intervention studies. Int J Obes Relat Metab Disord 2000; 24(12):1545-1552.

(673) Willett WC, Leibel RL. Dietary fat is not a major determinant of body fat. Am J Med 2002; 113 Suppl 9B:47S-59S.

(674) Astrup A. Carbohydrates as macronutrients in relation to protein and fat for body weight control. Int J Obes (Lond) 2006; 30 Suppl 3:S4-S9.

(675) Mensink RP, Katan MB. Effect of dietary fatty acids on serum lipids and lipoproteins. A meta-analysis of 27 trials. Arterioscler Thromb 1992; 12(8):911-919.

(676) Howard BV, Manson JE, Stefanick ML, Beresford SA, Frank G, Jones B et al. Low-Fat Dietary Pattern and Weight Change Over 7 Years: The Women's Health Initiative Dietary Modification Trial. JAMA 2006; 295(1):39-49.

(677) Zock PL. Do favourable effects of increasing unsaturated fat intake on cardiovascular disease risk outweigh the potential adverse effect on body weight? Int J Obes 2006; 30(S3):S10-S15.

(678) Warwick PM, Reid J. Trends in energy and macronutrient intakes, body weight and physical activity in female university students (1988-2003), and effects of excluding under-reporters. Br J Nutr 2004; 92(4):679-688.

(679) Boreham C, Twisk J, van Mechelen W, Savage M, Strain J, Cran G. Relationships between the development of biological risk factors for coronary heart disease and lifestyle parameters during adolescence: The Northern Ireland Young Hearts Project. Public Health 1999; 113(1):7-12.

(680) Colditz GA, Willett WC, Stampfer MJ, London SJ, Segal MR, Speizer FE. Patterns of weight change and their relation to diet in a cohort of healthy women. Am J Clin Nutr 1990; 51(6):1100-1105.

(681) Ludwig DS, Pereira MA, Kroenke CH, Hilner JE, Van Horn L, Slattery ML et al. Dietary fiber, weight gain, and cardiovascular disease risk factors in young adults. JAMA 1999; 282(16):1539-1546.

(682) Ma Y, Olendzki B, Chiriboga D, Hebert JR, Li Y, Li W et al. Association between Dietary Carbohydrates and Body Weight. Am J Epidemiol 2005; 161(4):359-367.

(683) Koppes LL, Boon N, Nooyens AC, van Mechelen W, Saris WH. Macronutrient distribution over a period of 23 years in relation to energy intake and body fatness. Br J Nutr 2009; 101(1):108-115.

(684) Hill JO, Prentice AM. Sugar and body weight regulation. Am J Clin Nutr 1995; 62(1 Suppl):264S-273S.

(685) Saris WH, Astrup A, Prentice AM, Zunft HJ, Formiguera X, Verboeket-van de Venne WP et al. Randomized controlled trial of changes in dietary carbohydrate/fat ratio and simple vs complex carbohydrates on body weight and blood lipids: the CARMEN study. The Carbohydrate Ratio Management in European National diets. Int J Obes Relat Metab Disord 2000; 24(10):1310-1318.

(686) Poppitt SD, Keogh GF, Prentice AM, Williams DE, Sonnemans HM, Valk EE et al. Long-term effects of ad libitum low-fat, high-carbohydrate diets on body weight and serum lipids in overweight subjects with metabolic syndrome. Am J Clin Nutr 2002; 75(1):11-20.

(687) Zijlstra N, Mars M, de Wijk RA, Westerterp-Plantenga MS, de Graaf C. The effect of viscosity on ad libitum food intake. Int J Obes 2008; 32(4):676-683.

(688) Mattes RD. Beverages and positive energy balance: the menace is the medium. Int J Obes 2006; 30(S3):S60-S65.

(689) Mourao DM, Bressan J, Campbell WW, Mattes RD. Effects of food form on appetite and energy intake in lean and obese young adults. Int J Obes (Lond) 2007.

(690) Pereira MA. The possible role of sugar-sweetened beverages in obesity etiology: a review of the evidence. Int J Obes 2006; 30(S3):S28-S36.

(691) Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. Am J Clin Nutr 2006; 84(2):274-288.

(692) Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA. Is sugar-sweetened beverage consumption associated with increased fatness in children? Nutrition 2007; 23(7-8):557-563.

(693) Libuda L, Alexy U, Sichert-Hellert W, Stehle P, Karaolis-Danckert N, Buyken AE et al. Pattern of beverage consumption and long-term association with body-weight status in German adolescents ? results from the DONALD study. British Journal of Nutrition 2008; 99(06):1370-1379.

(694) Dhingra R, Sullivan L, Jacques PF, Wang TJ, Fox CS, Meigs JB et al. Soft Drink Consumption and Risk of Developing Cardiometabolic Risk Factors and the Metabolic Syndrome in Middle-Aged Adults in the Community. Circulation 2007; 116(5):480-488.

(695) Forshee RA, Anderson PA, Storey ML. Sugar-sweetened beverages and body mass index in children and adolescents: a meta-analysis. Am J Clin Nutr 2008; 87(6):1662-1671.

(696) Koh-Banerjee P, Franz M, Sampson L, Liu S, Jacobs DR, Jr., Spiegelman D et al. Changes in whole-grain, bran, and cereal fiber consumption in relation to 8-y weight gain among men. Am J Clin Nutr 2004; 80(5):1237-1245.

(697) Liu S, Willett WC, Manson JE, Hu FB, Rosner B, Colditz G. Relation between changes in intakes of dietary fiber and grain products and changes in weight and development of obesity among middle-aged women. Am J Clin Nutr 2003; 78(5):920-927.

(698) Pereira MA, Ludwig DS. Dietary fiber and body-weight regulation. Observations and mechanisms. Pediatr Clin North Am 2001; 48(4):969-980.

(699) Bes-Rastrollo M, Martinez-Gonzalez MA, Sanchez-Villegas A, de la Fuente AC, Martinez JA. Association of fiber intake and fruit/vegetable consumption with weight gain in a Mediterranean population. Nutrition 2006; 22(5):504-511.

(700) Slavin JL, Martini MC, Jacobs DR, Jr., Marquart L. Plausible mechanisms for the protectiveness of whole grains. Am J Clin Nutr 1999; 70(3):459S-463.

(701) Miles CW. The metabolizable energy of diets differing in dietary fat and fiber measured in humans. J Nutr 1992; 122(2):306-311.

(702) Kristensen M, Damgaard TW, Sorensen AD, Raben A, Lindelov TS, Thomsen AD et al. Whole flaxseeds but not sunflower seeds in rye bread reduce apparent digestibility of fat in healthy volunteers. Eur J Clin Nutr 2007.

(703) Howarth NC, Saltzman E, Roberts SB. Dietary fiber and weight regulation. Nutr Rev 2001; 59(5):129-139.

(704) Jenkins DJ, Kendall CW, Augustin LS, Franceschi S, Hamidi M, Marchie A et al. Glycemic index: overview of implications in health and disease. Am J Clin Nutr 2002; 76(1):266S-273.

(705) Hare-Bruun H, Flint A, Heitmann BL. Glycemic index and glycemic load in relation to changes in body weight, body fat distribution, and body composition in adult Danes. Am J Clin Nutr 2006; 84(4):871-879.

(706) Jonas CR, McCullough ML, Teras LR, Walker-Thurmond KA, Thun MJ, Calle EE. Dietary Glycemic Index, Glycemic Load, and Risk of Incident Breast Cancer in Postmenopausal Women. Cancer Epidemiol Biomarkers Prev 2003; 12(6):573-577.

(707) Hare-Bruun H, Flint A, Heitmann BL. Glycemic index and glycemic load in relation to changes in body weight, body fat distribution, and body composition in adult Danes. Am J Clin Nutr 2006; 84(4):871-879.

(708) Hare-Bruun H, Flint A, Heitmann BL. Glycemic index and glycemic load in relation to changes in body weight, body fat distribution, and body composition in adult Danes. Am J Clin Nutr 2006; 84(4):871-879.

(709) Hare-Bruun H, Flint A, Heitmann BL. Glycemic index and glycemic load in relation to changes in body weight, body fat distribution, and body composition in adult Danes. Am J Clin Nutr 2006; 84(4):871-879.

(710) Hare-Bruun H, Flint A, Heitmann BL. Glycemic index and glycemic load in relation to changes in body weight, body fat distribution, and body composition in adult Danes. Am J Clin Nutr 2006; 84(4):871-879.

(711) Jonas CR, McCullough ML, Teras LR, Walker-Thurmond KA, Thun MJ, Calle EE. Dietary Glycemic Index, Glycemic Load, and Risk of Incident Breast Cancer in Postmenopausal Women. Cancer Epidemiol Biomarkers

Prev 2003; 12(6):573-577.

(712) Davis JN, Alexander KE, Ventura EE, Kelly LA, Lane CJ, Byrd-Williams CE et al. Associations of dietary sugar and glycemic index with adiposity and insulin dynamics in overweight Latino youth. Am J Clin Nutr 2007; 86(5):1331-1338.

(713) Sloth B, Krog-Mikkelsen I, Flint A, Tetens I, Bjorck I, Vinoy S et al. No difference in body weight decrease between a low-glycemic-index and a high-glycemic-index diet but reduced LDL cholesterol after 10-wk ad libitum intake of the low-glycemic-index diet. Am J Clin Nutr 2004; 80(2):337-347.

(714) Bouche C, Rizkalla SW, Luo J, Vidal H, Veronese A, Pacher N et al. Five-Week, Low-Glycemic Index Diet Decreases Total Fat Mass and Improves Plasma Lipid Profile in Moderately Overweight Nondiabetic Men. Diabetes Care 2002; 25(5):822-828.

(715) Wolever TM, Mehling C. High-carbohydrate-low-glycaemic index dietary advice improves glucose disposition index in subjects with impaired glucose tolerance. Br J Nutr 2002; 87(5):477-487.

(716) Ebbeling CB, Leidig MM, Sinclair KB, Seger-Shippee LG, Feldman HA, Ludwig DS. Effects of an ad libitum low-glycemic load diet on cardiovascular disease risk factors in obese young adults. Am J Clin Nutr 2005; 81(5):976-982.

(717) Aston LM, Stokes CS, Jebb SA. No effect of a diet with a reduced glycaemic index on satiety, energy intake and body weight in overweight and obese women. Int J Obes (Lond) 2008; 32(1):160-165.

(718) Storlien LH, Huang XF, Lin S, Xin X, Wang HQ, Else PL. Dietary fat subtypes and obesity. World Rev Nutr Diet 2001; 88:148-154.

(719) Kavanagh K, Jones KL, Sawyer J, Kelley K, Carr JJ, Wagner JD et al. Trans fat diet induces abdominal obesity and changes in insulin sensitivity in monkeys. Obesity (Silver Spring) 2007; 15(7):1675-1684.

(720) Field AE, Willett WC, Lissner L, Colditz GA. Dietary fat and weight gain among women in the Nurses' Health Study. Obesity (Silver Spring) 2007; 15(4):967-976.

(721) Oken E, Taveras EM, Popoola FA, Rich-Edwards JW, Gillman MW. Television, walking, and diet: associations with postpartum weight retention. Am J Prev Med 2007; 32(4):305-311.

(722) Alfenas RC, Mattes RD. Effect of fat sources on satiety. Obes Res 2003; 11(2):183-187.

(723) Flint A, Helt B, Raben A, Toubro S, Astrup A. Effects of different dietary fat types on postprandial appetite and energy expenditure. Obes Res 2003; 11(12):1449-1455.

(724) Halkjaer J, Tjonneland A, Thomsen BL, Overvad K, Sorensen TI. Intake of macronutrients as predictors of 5-y changes in waist circumference. Am J Clin Nutr 2006; 84(4):789-797.

(725) Skov AR, Toubro S, Ronn B, Holm L, Astrup A. Randomized trial on protein vs carbohydrate in ad libitum fat reduced diet for the treatment of obesity. Int J Obes Relat Metab Disord 1999; 23(5):528-536.

(726) Due A, Toubro S, Skov AR, Astrup A. Effect of normal-fat diets, either medium or high in protein, on body weight in overweight subjects: a randomised 1-year trial. Int J Obes Relat Metab Disord 2004; 28(10):1283-1290.

(727) Weigle DS, Breen PA, Matthys CC, Callahan HS, Meeuws KE, Burden VR et al. A high-protein diet induces sustained reductions in appetite, ad libitum caloric intake, and body weight despite compensatory changes in diurnal plasma leptin and ghrelin concentrations. Am J Clin Nutr 2005; 82(1):41-48.

(728) Long SJ, Jeffcoat AR, Millward DJ. Effect of habitual dietary-protein intake on appetite and satiety. Appetite 2000; 35(1):79-88.

(729) Yeomans MR. Effects of alcohol on food and energy intake in human subjects: evidence for passive and active over-consumption of energy. Br J Nutr 2004; 92 Suppl 1:S31-S34.

(730) Wannamethee SG, Shaper AG. Alcohol, body weight, and weight gain in middle-aged men. Am J Clin Nutr 2003; 77(5):1312-1317.

(731) Tolstrup JS, Halkjaer J, Heitmann BL, Tjonneland AM, Overvad K, Sorensen TI et al. Alcohol drinking frequency in relation to subsequent changes in waist circumference. Am J Clin Nutr 2008; 87(4):957-963.

(732) Pedro M, Michèle M, Bernadette H, Annie B, Alun E, Irène J et al. Relationships between alcoholic beverages and cardiovascular risk factor levels in middle-aged men, the PRIME study. Atherosclerosis 157[2], 431-440. 1-8-2001.
Ref Type: Abstract

(733) Trowman R, Dumville JC, Hahn S, Torgerson DJ. A systematic review of the effects of calcium supplementation on body weight. Br J Nutr 2006; 95(6):1033-1038.

(734) He K, Hu FB, Colditz GA, Manson JE, Willett WC, Liu S. Changes in intake of fruits and vegetables in relation to risk of obesity and weight gain among middle-aged women. Int J Obes Relat Metab Disord 2004; 28(12):1569-1574.

(735) Newby PK, Muller D, Hallfrisch J, Andres R, Tucker KL. Food patterns measured by factor analysis and anthropometric changes in adults. Am J Clin Nutr 2004; 80(2):504-513.

(736) Sanchez-Villegas A, Bes-Rastrollo M, Martinez-Gonzalez MA, Serra-

Majem L. Adherence to a Mediterranean dietary pattern and weight gain in a follow-up study: the SUN cohort. Int J Obes (Lond) 2006; 30(2):350-358.

(737) Schulz M, Nothlings U, Hoffmann K, Bergmann MM, Boeing H. Identification of a Food Pattern Characterized by High-Fiber and Low-Fat Food Choices Associated with Low Prospective Weight Change in the EPIC-Potsdam Cohort. J Nutr 2005; 135(5):1183-1189.

(738) Schulze MB, Fung TT, Manson JE, Willett WC, Hu FB. Dietary Patterns and Changes in Body Weight in Women. Obesity Res 2006; 14(8):1444-1453.

(739) Woo J, Cheung B, Ho S, Sham A, Lam TH. Influence of dietary pattern on the development of overweight in a Chinese population. Eur J Clin Nutr 2008; 62(4):480-487.

(740) Ledikwe JH, Ello-Martin JA, Rolls BJ. Portion sizes and the obesity epidemic. J Nutr 2005; 135(4):905-909.

(741) Rolls BJ, Roe LS, Meengs JS. Larger portion sizes lead to a sustained increase in energy intake over 2 days. J Am Diet Assoc 2006; 106(4):543-549.

(742) Rolls BJ, Roe LS, Meengs JS. The effect of large portion sizes on energy intake is sustained for 11 days. Obesity (Silver Spring) 2007; 15(6):1535-1543.

(743) Ello-Martin JA, Ledikwe JH, Rolls BJ. The influence of food portion size and energy density on energy intake: implications for weight management. Am J Clin Nutr 2005; 82(1):236S-241.

(744) Ebbeling CB, Garcia-Lago E, Leidig MM, Seger-Shippee LG, Feldman HA, Ludwig DS. Altering portion sizes and eating rate to attenuate gorging during a fast food meal: effects on energy intake. Pediatrics 2007; 119(5):869-875.

(745) Bazzano LA, Song Y, Bubes V, Good CK, Manson JE, Liu S. Dietary Intake of Whole and Refined Grain Breakfast Cereals and Weight Gain in Men. Obesity Res 2005; 13(11):1952-1960.

(746) van der Heijden AAWA, Hu FB, Rimm EB, van Dam RM. A Prospective Study of Breakfast Consumption and Weight Gain among U.S. Men. Obesity Res 2007; 15(10):2463-2469.

(747) Timlin MT, Pereira MA, Story M, Neumark-Sztainer D. Breakfast Eating and Weight Change in a 5-Year Prospective Analysis of Adolescents: Project EAT (Eating Among Teens). Pediatrics 2008; 121(3):e638-e645.

(748) Berkey CS, Rockett HR, Gillman MW, Field AE, Colditz GA. Longitudinal study of skipping breakfast and weight change in adolescents. Int J Obes Relat Metab Disord 2003; 27(10):1258-1266.

(749) Purslow LR, Sandhu MS, Forouhi N, Young EH, Luben RN, Welch AA et al. Energy Intake at Breakfast and Weight Change: Prospective Study of 6,764 Middle-aged Men and Women. Am J Epidemiol 2008; 167(2):188-192.

(750) Prentice AM. Manipulation of dietary fat and energy density and subsequent effects on substrate flux and food intake. Am J Clin Nutr 1998; 67(3):535S-5541.

(751) Stubbs RJ, Ritz P, Coward WA, Prentice AM. Covert manipulation of the ratio of dietary fat to carbohydrate and energy density: effect on food intake and energy balance in free-living men eating ad libitum. Am J Clin Nutr 1995; 62(2):330-337.

(752) Stubbs RJ, Harbron CG, Murgatroyd PR, Prentice AM. Covert manipulation of dietary fat and energy density: effect on substrate flux and food intake in men eating ad libitum. Am J Clin Nutr 1995; 62(2):316-329.

(753) Murgatroyd PR, Goldberg GR, Leahy FE, Gilsenan MB, Prentice AM. Effects of inactivity and diet composition on human energy balance. Int J Obes Relat Metab Disord 1999; 23(12):1269-1275.

(754) Stubbs RJ, Hughes DA, Johnstone AM, Horgan GW, King N, Blundell JE. A decrease in physical activity affects appetite, energy, and nutrient balance in lean men feeding ad libitum. Am J Clin Nutr 2004; 79(1):62-69.

(755) Mayer J. Some aspects of the problem of regulation of food intake and obesity. N Engl J Med 1966; 274(13):722-731.

(756) Hill JO. Understanding and Addressing the Epidemic of Obesity: An Energy Balance Perspective. Endocr Rev 2006; 27(7):750-761.

(757) Melzer K, Kayser B, Saris WH, Pichard C. Effects of physical activity on food intake. Clinical nutrition (Edinburgh, Scotland) 24[6], 885-895. 1-12-2005.
Ref Type: Abstract

(758) Elder SJ, Roberts SB. The effects of exercise on food intake and body fatness: a summary of published studies. Nutr Rev 2007; 65(1):1-19.

(759) Blundell JE, Stubbs RJ, Hughes DA, Whybrow S, King NA. Cross talk between physical activity and appetite control: does physical activity stimulate appetite? Proc Nutr Soc 2003; 62(3):651-661.

(760) King NA, Caudwell P, Hopkins M, Byrne NM, Colley R, Hills AP et al. Metabolic and Behavioral Compensatory Responses to Exercise Interventions: Barriers to Weight Loss. Obesity Res 2007; 15(6):1373-1383.

(761) Martins C, Morgan L, Truby H. A review of the effects of exercise on appetite regulation: an obesity perspective. Int J Obes (Lond) 2008; 32(9):1337-1347.

(762) Martins C, Robertson MD, Morgan LM. Effects of exercise and restrained eating behaviour on appetite control. Proceedings of the Nutrition Society 2008; 67(01):28-41.

(763) Long SJ, Hart K, Morgan LM. The ability of habitual exercise to influence appetite and food intake in response to high- and low-energy preloads in man. Br J Nutr 2002; 87(5):517-523.

(764) King NA, Appleton K, Rogers PJ, Blundell JE. Effects of sweetness and energy in drinks on food intake following exercise. Physiol Behav 1999; 66(2):375-379.

(765) Torun B. Energy requirements of children and adolescents. Public Health Nutr 2005; 8(7A):968-993.

(766) Anderson SE, Bandini LG, Dietz WH, Must A. Relationship between temperament, nonresting energy expenditure, body composition, and physical activity in girls. Int J Obes Relat Metab Disord 2004; 28(2):300-306.

(767) Arvidsson D, Slinde F, Hulthen L. Physical activity questionnaire for adolescents validated against doubly labelled water. Eur J Clin Nutr 2005; 59(3):376-383.

(768) Bandini LG, Must A, Spadano JL, Dietz WH. Relation of body composition, parental overweight, pubertal stage, and race-ethnicity to energy expenditure among premenarcheal girls. Am J Clin Nutr 2002; 76(5):1040-1047.

(769) Bratteby LE, Sandhagen B, Samuelson G. Physical activity, energy expenditure and their correlates in two cohorts of Swedish subjects between adolescence and early adulthood. Eur J Clin Nutr 2005; 59(11):1324-1334.

(770) Craig SB, Bandini LG, Lichtenstein AH, Schaefer EJ, Dietz WH. The impact of physical activity on lipids, lipoproteins, and blood pressure in preadolescent girls. Pediatrics 1996; 98(3 Pt 1):389-395.

(771) Delany JP, Bray GA, Harsha DW, Volaufova J. Energy expenditure and substrate oxidation predict changes in body fat in children. Am J Clin Nutr 2006; 84(4):862-870.

(772) Goran MI, Carpenter WH, Poehlman ET. Total energy expenditure in 4- to 6-yr-old children. Am J Physiol 1993; 264(5 Pt 1):E706-E711.

(773) Hernandez-Triana M, Salazar G, Diaz E, Sanchez V, Basabe B, Gonzalez S et al. Total energy expenditure by the doubly-labeled water method in rural preschool children in Cuba. Food Nutr Bull 2002; 23(3 Suppl):76-81.

(774) Hoos MB, Plasqui G, Gerver WJ, Westerterp KR. Physical activity level measured by doubly labeled water and accelerometry in children. Eur J Appl Physiol 2003; 89(6):624-626.

(775) Lindquist CH, Cummings T, Goran MI. Use of tape-recorded food records

in assessing children's dietary intake. Obes Res 2000; 8(1):2-11.

(776) Lopez-Alarcon M, Merrifield J, Fields DA, Hilario-Hailey T, Franklin FA, Shewchuk RM et al. Ability of the actiwatch accelerometer to predict free-living energy expenditure in young children. Obes Res 2004; 12(11):1859-1865.

(777) McGloin AF, Livingstone MB, Greene LC, Webb SE, Gibson JM, Jebb SA et al. Energy and fat intake in obese and lean children at varying risk of obesity. Int J Obes Relat Metab Disord 2002; 26(2):200-207.

(778) Montgomery C, Reilly JJ, Jackson DM, Kelly LA, Slater C, Paton JY et al. Validation of energy intake by 24-hour multiple pass recall: comparison with total energy expenditure in children aged 5-7 years. Br J Nutr 2005; 93(5):671-676.

(779) Perks SM, Roemmich JN, Sandow-Pajewski M, Clark PA, Thomas E, Weltman A et al. Alterations in growth and body composition during puberty. IV. Energy intake estimated by the youth-adolescent food-frequency questionnaire: validation by the doubly labeled water method. Am J Clin Nutr 2000; 72(6):1455-1460.

(780) Roemmich JN, Clark PA, Walter K, Patrie J, Weltman A, Rogol AD. Pubertal alterations in growth and body composition. V. Energy expenditure, adiposity, and fat distribution. Am J Physiol Endocrinol Metab 2000; 279(6):E1426-E1436.

(781) Rush EC, Plank LD, Davies PS, Watson P, Wall CR. Body composition and physical activity in New Zealand Maori, Pacific and European children aged 5-14 years. Br J Nutr 2003; 90(6):1133-1139.

(782) Sjoberg A, Slinde F, Arvidsson D, Ellegard L, Gramatkovski E, Hallberg L et al. Energy intake in Swedish adolescents: validation of diet history with doubly labelled water. Eur J Clin Nutr 2003; 57(12):1643-1652.

(783) Sun M, Gower BA, Nagy TR, Bartolucci AA, Goran MI. Do hormonal indices of maturation explain energy expenditure differences in African American and Caucasian prepubertal children? Int J Obes Relat Metab Disord 1999; 23(12):1320-1326.

(784) Paul AA, Black AE, Evans J, Cole TJ, Whitehead RG. Breast milk intake and growth in infants from 2 to 10 months. J Hum Nutr Dietet 1988; 1:437-450.

(785) Sadurskis A, Kabir N, Wager J, Forsum E. Energy metabolism, body composition, and milk production in healthy Swedish women during lactation. Am J Clin Nutr 1988; 48(1):44-49.