

Physical Activity

Physical activity is defined as any bodily movement produced by the contraction of skeletal muscles resulting in energy expenditure . Physical activity is a complex and multi-dimensional behaviour taking place in a variety of domains: in transportation, domestic life, occupation and recreation . The dimensions of a physical activity are defined as its volume, frequency, intensity, time and type.

Physical activity and disease risk

Prospective studies in which occupational and leisure physical activity were assessed by questionnaire established that physical inactivity was an independent risk factor for coronary heart disease; people who were regularly active had up to half the risk of those who are sedentary .

Increased self-reported physical activity has also been associated with a reduced risk for type 2 diabetes , stroke , lung cancer colorectal cancer postmenopausal breast cancer and endometrial cancer .

The observational studies that have reported these associations have relied on self-reported physical activity, which does not provide accurate estimates of absolute amounts of activity and cannot, therefore, determine whether higher levels of activity-induced energy expenditure confer survival advantages .

Objective measures of physical activity avoid known misclassification biases that occur with self-reported physical activity questionnaires . Some prospective studies have used measures of cardiorespiratory fitness as a proxy for physical activity. Cardiorespiratory fitness assessments (peak exercise oxygen consumption) are objective measurements and are an indication of physical activity during the weeks and months preceding the test , but may also be influenced by other environmental and genetic factors . Cardiorespiratory fitness can be improved in a dose-response fashion by exercise training .

Cardiorespiratory fitness has been shown to be a strong and independent predictor of type 2 diabetes , CVD risk factors CVD morbidity and mortality , cancer mortality and all-cause mortality .

These studies have generally shown stronger associations with health outcomes than did studies with self-reported physical activity as the exposure, but they are not definitive in describing the amounts and types of physical activity or the amount of energy expenditure associated with decreased disease risk .

In a prospective study of healthy older adults (n=302; aged 70 to 79 years) TEE was determined using the DLW technique and RMR by indirect calorimetry . Over an average of 6.15 years of follow-up, participants in the upper tertile of PAEE (PAL >1.78) had a reduced risk of all-cause mortality (HR 0.43, 95% CI 0.21-0.88; $P_{\text{trend}} = 0.02$) than those in the lowest tertile (PAL <1.57). Objectively measured free-living PAEE was strongly associated with lower risk of all-cause mortality in healthy older adults. The intensity and type of physical activity was not objectively measured, but physical activity questionnaires suggested that the

proportion of individuals who reported high-intensity exercise and walking for exercise (both in terms of duration and intensity) was similar across tertiles of free-living activity energy expenditure. It was concluded that simply expending energy through any activity may influence survival in older adults, seemingly contradicting reports that exercise needs to be performed at a specific intensity to produce health benefits .

In children, there is cross-sectional evidence to suggest that physical activity and cardiorespiratory fitness are separately and independently associated with individual and clustered metabolic risk factors (waist circumference, blood pressure, fasting glucose, insulin, triacylglycerol and HDL-cholesterol levels) , but prospective studies are required to confirm this observation. One prospective study in adults with a family history of type 2 diabetes (n=393), observed that an increase in objectively measured PAEE (heart rate monitoring) between baseline to follow-up (5.6 years) was associated with reduced metabolic risk factor concentrations (blood pressure, fasting triglycerides, HDL cholesterol, insulin, and glucose) independently of aerobic fitness . Both the non-exercise and exercise components of PAEE may be important determinants of longevity . The use of semiquantitative food frequency questionnaires to assess non-exercise physical activity is, however, limited .

Randomized controlled trials have shown that exercise training programs reduce blood pressure , beneficially affect dyslipidemia and, in high-risk populations (e.g. with impaired glucose tolerance) reduce insulin resistance and prevent or postpone the onset of type 2 diabetes . Exercise-based cardiac rehabilitation programmes have been shown to be effective in reducing the risk of premature mortality in patients with coronary heart disease .

Overall, adults with higher levels of fitness or reported physical activity tend to have lower mortality risk than their unfit and inactive peers within the same body mass index group. Accumulating evidence suggests that higher physical activity or fitness attenuates the health risks of obesity . Prospective evidence also suggests that body weight may have a greater influence on diabetes risk, and physical activity plays a greater role in cardiovascular disease risk .

In the UK, adults are recommended to have at least 30 minutes a day of moderate intensity physical activity (similar to brisk walking) for general health. 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 . 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.

Proportion of UK population achieving physical activity recommendations

Adults

The Health Survey for England (HSE) reports on physical activity data collected since 1997 . In 2004, 6,692 completed questionnaires were obtained from respondents, 3,256 men and 3,436 women; 37% of men and 25% of women reported achieving the physical activity recommendations for adults.

Table 1. Proportion of adults aged 16 and over achieving the physical activity target, 1997, 1998, 2003, 2004, by age and sex in the HSE

	Age							Total
	16-24	25-34	35-44	45-54	55-64	65-74	75+	
	%	%	%	%	%	%	%	%
Men								
1997	49	41	37	32	23	12	7	32
1998	53	45	41	34	30	14	6	34
2003 (unweighted)*	53	44	41	37	32	17	8	35
2004 (unweighted)*	56	46	41	37	32	19	9	35
2003 (weighted)	52	44	41	38	32	17	8	36
2004 (weighted)	56	46	41	37	32	18	8	37
Women								
1997	26	26	29	24	19	8	5	21
1998	28	28	28	25	18	9	3	21
2003 (unweighted)*	30	29	30	30	23	13	3	24
2004 (unweighted)*	31	31	33	29	19	14	4	24
2003 (weighted)	30	29	30	31	23	13	3	24
2004 (weighted)	32	30	32	30	20	14	4	25
Base								
Men								
1997	492	739	740	694	535	455	243	3898
1998	875	1338	1305	1289	987	837	562	7193
2003 (unweighted)	744	1024	1260	1098	1097	807	551	6581
2004 (unweighted)	291	446	535	439	508	378	276	2873
2003 (weighted)	1044	1272	1412	1180	1037	731	501	7177
2004 (weighted)	485	556	647	530	477	329	231	3256
Women								
1997	560	916	833	806	585	545	439	4684
1998	1006	1630	1573	1484	1148	967	907	8715
2003 (unweighted)	886	1279	1615	1278	1304	948	900	8210
2004 (unweighted)	364	550	746	626	621	482	429	3818
2003 (weighted)	1029	1279	1437	1199	1071	813	782	7611
2004 (weighted)	472	563	653	541	491	364	353	3436

* Data from 2003 onwards have been weighted for non-response. Unweighted data for 2003 onwards are provided for consistency with previous years which are also unweighted. For data comparability across HSE years, only activity sessions that lasted at least 30 minutes were included.

The HSE reports on trends in physical activity from 1997, 1998, 2003 and 2004. The questionnaires used in the 2003 and 2004 survey were shorter than the surveys in 1997 and 1998, therefore, results from these two years have been recalculated to allow for comparisons to be made. For both men and women, the proportion achieving physical activity recommendations has increased overall, from 32% in 1997 to 35% in 2004 for men, and from 21% to 24% for women. This perhaps presents a paradox given the rising prevalence of obesity.

For both men and women in 2004, the proportion meeting the guidelines decreased steadily with age, from 56% of those aged 16 to 24, to 9% for those aged 75 and over among men. The proportion of women meeting the guidelines remained stable for women aged 16 to 54 (29-33%) and decreased thereafter to 4% among women 75 and over. Men aged 16-24 are the

group most likely to meet physical activity targets and are also the least likely group to be obese.

In the 1991 to 1994 HSE, physical activity was examined as occasions, rather than days (as in 1997 to 2004), that respondents took part in heavy domestic (heavy housework, heavy DIY/gardening), walking, and sports (see the Temporal trends in physical activity section below).

The Allied Dunbar National Fitness Survey in 1990 measured physical activity patterns and fitness levels of adults in England, achieving a sample size of over 4,000 people. Similar to the HSE, the survey measured levels of participation in sport and active recreation, physical activity in housework, DIY and gardening in the previous four weeks. Activities were classified as either light, moderate or of vigorous intensity. A six point activity level scale was then devised using information about duration, frequency and intensity. Physical activity targets were defined for different age groups based on varying levels of intensity and activity, which lasted 20 minutes or more. The main findings from the survey reported that 7 out of 10 men and 8 out of 10 women fell below their age appropriate activity level necessary to achieve a health benefit.

The NDNS of adults aged 19-64 years, 2000/1, was the first of the NDNS series to collect data on physical activity. The HSE used a seven-day recall method to assess physical activity, compared with the NDNS, which used a seven-day diary; also, activities lasting less than 15 minutes were excluded in the HSE, while activities lasting less than 10 minutes were excluded in the NDNS.

Complete seven-day physical activity diaries were obtained from 1,658 respondents, 741 men and 917 women in the NDNS. Overall, 36% of men and 26% of women spent 30 minutes or more per day in activities of at least moderate intensity on five or more days, which is very similar to the HSE results. For men, the proportion who achieved the physical activity recommendation decreased with age, whereas, for women, there were no significant age differences (see Table 2).

Table 2. The proportion of adults aged 19-64 achieving the physical activity target, 2000/1, by age and sex in the NDNS

	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

Children and adolescents

The HSE 2002, shows 70% of boys and 61% of girls met current physical activity guidelines for children (achieving 60 minutes or more of at least moderate intensity physical activity a day). The HSE 2002 was the most recent data available with a large enough sample size for

children to carry out a detailed analysis.

Information from the HSE 2002 is presented on the participation in out of school physical activity and the physical activity levels of children aged 2 to 15. Data on the physical activity that children do as part of the school curriculum is available from the School Sport Survey .

The structure of the physical activity questionnaire was considerably different between 1997 and 2002. To make 2002 data more comparable with 1997 data, only activities that lasted at least 15 minutes were included in the trend analysis. In addition, all walking and housework and gardening sessions in 2002 were capped at 15 minutes to make the data more comparable with 1997.

There were no significant differences in the proportions of boys and girls aged 2 to 10 and 11 to 15 meeting the physical activity target of at least 60 minutes of activity each day between 1997 and 2002. Differences do emerge, however, when considering the proportion of those who did at least 30 minutes of activity each day of the week. For example, the proportion of boys aged 2 to 10 who did between 30 and 59 minutes activity each day of the week increased from 9% in 1997 to 20% in 2002. For girls aged 2 to 10 there was an increase from 10% to 21% over the same period.

Physical activity was objectively measured (using accelerometry) in 11 to 12 year olds (n=5,595) from the southwest of England . The median time spent in moderate to vigorous physical activity in this study is 20 minutes per day (boys: 25 minutes per day; girls: 16 minutes per day). There was substantial intra-individual variation in the measures physical activity of these children . 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 and American children , 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.

Using accelerometers, it was also found that children from a deprived inner city school were active at recommended levels and had similar levels of activity to children in other studies from more affluent populations . These findings, also, were dependent on the threshold used to define moderate physical activity.

UK population PAL values

The previous DRV for food energy report assumed, in the absence of any reliable information, that UK adult population groups had a PAL value of 1.4, due to the inactive lifestyle of much of the population . This value was then used for the basis of the EAR of energy for adults. Children aged 10-18 years were assumed to have slightly higher PAL values of 1.56 for boys and 1.48 for girls; this was based on provisional information on the time use and energy cost of activities in the school day. For younger children insufficient information was available.

It has been suggested that the energy costs of activity used in the report to calculate energy expenditure underestimate those achieved during active leisure in individuals who take regular exercise and that PAL values for active subjects tend to be higher than those assumed in the report .

Adults

It was not possible to derive PAL values from the HSE because the survey did not record the amount of 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.

Table 3. Distribution of PAL values for adults aged 19-64 years derived from seven-day physical activity questionnaire in the NDNS

	Age				Total
	19-24	25-34	35-49	50-64	
Men					
Mean PAL	1.93	1.94	1.86	1.77	1.85
	%	%	%	%	%
1.3	0.00	0.00	0.00	0.00	0.00
1.4	0.00	0.00	0.71	1.85	0.86
1.5	0.00	2.78	1.41	1.39	1.58
1.6	20.37	10.42	13.78	21.30	15.93
1.7	22.22	28.47	34.28	36.57	32.86
1.8	9.26	12.50	9.89	11.57	10.90
1.9	5.56	6.25	4.24	5.09	5.02
2.0	5.56	9.72	11.66	4.17	8.46
2.1	12.96	4.86	5.65	6.02	6.17
2.2	5.56	5.56	4.59	5.09	5.02
2.3	1.85	0.69	1.77	0.93	1.29
2.4	1.85	3.47	1.77	0.46	1.72
2.5	3.70	2.08	3.18	0.93	2.30
>2.5	11.11	13.19	7.07	4.63	7.89
No of subjects	54	144	283	216	697
Women					
Mean PAL	1.72	1.71	1.72	1.66	1.70
	%	%	%	%	%
1.3	0.00	0.53	0.00	0.00	0.12
1.4	0.00	0.00	0.00	0.00	0.00
1.5	1.52	1.60	1.17	3.08	1.87
1.6	28.79	26.20	28.45	33.85	29.63
1.7	33.33	33.69	33.14	40.00	35.36
1.8	13.64	16.04	12.32	9.62	12.41
1.9	6.06	6.95	7.33	6.15	6.79
2.0	6.06	6.95	9.68	5.00	7.38
2.1	6.06	3.74	2.64	1.54	2.81
2.2	0.00	1.07	1.76	0.38	1.05
2.3	1.52	1.60	0.59	0.00	0.70
2.4	1.52	0.00	1.47	0.00	0.70
2.5	0.00	0.00	0.29	0.38	0.23
>2.5	1.52	1.60	1.17	0.00	0.94
No of subjects	66	187	341	260	854

Percentages may not add to 100 due to rounding

Table 4. Distribution of PAL values by weight category for women aged 19-64 years derived from seven-day physical activity questionnaire in the NDNS

	Percentages				
	Underweight	Ideal	Overweight	Obese	Total
Mean PAL	1.74	1.70	1.71	1.68	1.70
1.3	0	0	0	0	0
1.4	0	0	0	0	0
1.5	2	1	3	2	2
1.6	28	29	26	37	30
1.7	34	34	35	39	35
1.8	11	13	16	7	12
1.9	8	9	6	5	7
2.0	6	8	7	7	7
2.1	4	3	3	1	3
2.2	2	1	1	1	1
2.3	0	1	1	0	1
2.4	4	0	1	1	1
2.5	0	0	1	0	0
>2.5	2	1	1	1	1
No of subjects	53	338	287	176	854

Percentages may not add to 100 due to rounding

Table 5. Distribution of PAL values by weight category for men aged 19-64 years derived from seven-day physical activity questionnaire in the NDNS

	Percentages				
	Underweight	Ideal	Overweight	Obese	Total
Mean PAL	1.76	1.88	1.83	1.87	1.85
1.3	0	0	0	0	0
1.4	0	0	1	2	1
1.5	10	1	2	1	2
1.6	25	14	16	17	16
1.7	20	32	36	30	33
1.8	15	11	11	10	11
1.9	10	5	6	3	5
2.0	15	7	8	11	8
2.1	0	6	5	8	6
2.2	0	8	3	5	5
2.3	0	2	1	1	1
2.4	0	3	1	1	2
2.5	0	3	2	3	2
>2.5	5	7	8	8	8
No of subjects	20	204	305	168	697

Percentages may not add to 100 due to rounding

Participants recorded time spent sleeping, at work and participating in listed leisure, sports

and other activities. The total time spent in sleep, light, moderate and vigorous intensity activities was multiplied by a metabolic equivalent (MET) value to give total MET hours of activity per day. The MET values used were: sleep 1.0; light 2.0; moderate 3.5; vigorous 6.0. These were summed to give a mean MET score for the week and then divided by 24 hours to give the PAL.

An unpublished validation study for the seven-day physical activity questionnaire was conducted prior to the main adult survey on a sample of 66 adults. This study included a doubly labelled water (DLW) assessment of energy expenditure as well as dietary and activity records. PAL values for each subject were derived from both seven-day activity records and from energy expenditure derived from DLW measurements (see Tables 6 & 7); BMR was calculated using the modified Schofield equations.

Table 6. Distribution of PAL values for adults aged 19-64 years derived from validation study energy expenditure data

	19-64 years		
	Men	Women	Men & Women
Mean PAL	1.88	1.74	1.79
	%	%	
1.3	0.00	0.00	0.00
1.4	4.35	6.98	6.06
1.5	0.00	11.63	7.58
1.6	13.04	9.30	10.61
1.7	13.04	16.28	15.15
1.8	17.39	16.28	16.67
1.9	13.04	13.95	13.64
2.0	13.04	11.63	12.12
2.1	4.35	11.63	9.09
2.2	0.00	2.33	1.52
2.3	8.70	0.00	3.03
2.4	4.35	0.00	1.52
2.5	8.70	0.00	3.03
>2.5	0.00	0.00	0.00
No of subjects	23	43	66

Percentages may not add to 100 due to rounding

PAL = TEE / BMR (calculated)

Table 7. Distribution of PAL values for adults aged 19-64 years derived from validation study activity records

	19-64 years		
	Men	Women	Men & Women
Mean PAL	1.88	1.74	1.79
	%	%	
1.3	0.00	0.00	0.00
1.4	0.00	0.00	0.00
1.5	0.00	5.13	3.33
1.6	23.81	30.77	28.33
1.7	38.10	43.59	41.67
1.8	9.52	10.26	10.00
1.9	9.52	5.13	6.67
2.0	9.52	5.13	6.67
2.1	0.00	0.00	0.00
2.2	0.00	0.00	0.00
2.3	4.76	0.00	1.67
2.4	0.00	0.00	0.00
2.5	0.00	0.00	0.00
>2.5	4.76	0.00	1.67
No of subjects	23	43	66

Percentages may not add to 100 due to rounding

PAL = TEE / BMR (calculated)

The mean PAL values derived by the two methods were similar at 1.8-1.9 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.

Considering that only 36% of men and 26% of women meet the 30 min 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, which has been recommended as required to prevent the transition to overweight or obesity, corresponds to an approximate PAL value of 1.7 .

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 the physical activity recommendation. The NDNS methodology is thought to overestimate activity in people with low activity levels.

It has been suggested that many physical activity questionnaires have an arbitrary grading in their classification of relative activities and do not necessarily reflect the true total energy expenditure, which results in an overestimation .

The NDNS data did not show any consistent differences between PAL values of different weight categories: underweight, ideal, overweight and obese (see Tables 4 & 5).

Children and adolescents

No survey data of PAL values for children and adolescents are available.

Temporal trends in physical activity in the UK

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. For example, there has been a massive change 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. 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.

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. 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.

A 5-year prospective study in London, of a diverse cohort of children aged 11–12 years at baseline in 1999 (n=5863), observed marked reductions in physical activity and increases in sedentary behaviour between ages 11–12 and 15–16 years. Physical activity declined and sedentary behaviour became more common during adolescence, although little evidence was found of new cases of overweight or obesity emerging over this period. A decline in physical activity and an increase in sedentary behaviours in adolescence has also been observed in other populations.

The HSE has been collecting multiple-domain physical activity data, since 1991. An analysis of the HSE physical activity data was performed to estimate temporal trends of participation in physical activity between 1991 to 2004, a period when the prevalence of obesity in adults living in England rose by over 65%. 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. 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).

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. 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.

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. In Scotland and Wales, there was an increase in the percentage of schoolchildren who reported undertaking vigorous physically active at least four times a week between 1985/86 and 1997/98, followed by a decline in 2001/02. The proportions watching 4 h of TV daily changed little between 1985/86 and 1997/98 as did the. Children in

Wales were most likely to report higher levels of TV watching across all four surveys.

Increased sedentary behaviours, e.g. increases in the average time spent watching television, have been suggested as a factor influencing the increase in obesity. 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 physical activity levels; equally, computer use could have replaced time spent in other sedentary activities, such as listening to the radio or music, watching television and reading, and not impacted on overall activity levels. A survey of 3601 children in Leicester observed that almost half (46%) of respondents spent four or more hours per day watching television or videos or playing computer games.

A meta-analysis was 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. The only significant relationship observed was between TV 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.

Several prospective studies since the meta-analysis have also observed positive associations between television viewing in children and subsequent weight gain. 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.

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.

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. 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 and people tend to snack while watching television.

Physical activity and body fatness

Intuitively, the energy expended during physical activity would appear to be an important factor in maintaining energy balance. PAEE is the most variable component of TEE and is amenable to modification. The rising prevalence of obesity has been attributed in part to population-level changes in physical activity.

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 . 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 .

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

There are essentially three lines of evidence: associations of self-reported PA and weight change/body fatness; assessment of objectively measured PA (e.g. Cardiorespiratory Fitness/accelerometry/DLW as a Predictor) and weight change/body fatness; and interventions to increase PA to reduce weight gain

Prospective studies of self-reported physical activity and weight gain

The prospective studies relating physical activity and weight change were systematically reviewed in 2000 both in adults and children ; 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 .

Adults

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 range of participants was 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.

Overall, two studies reported a consistent inverse association between baseline physical activity and subsequent weight gain ; whereas, three did not and one found a positive association . One study observed a positive association for men and a negative association for women between baseline physical activity and subsequent weight gain . Jogging or running, but not other less strenuous activities, were inversely associated with weight gain in one study .

There were seven studies that found an increase in physical activity between baseline and follow-up was associated with less weight gain and two did not . Four studies found that a large volume of physical activity at follow-up was associated with less weight gain , while one did not . In one study the cumulative duration of increased physical activity was observed not to be associated with weight change .

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 .

A follow-up systematic review 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 and two found no association. One study reported an inverse association suggesting higher baseline levels of BMI predicted physical inactivity. 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 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.

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.

A study not included in the systematic review conducted a prospective evaluation (5.5 years follow-up) of subjects (n=496) attending an employee health-related fitness programme observed increased self-reported physical activity to be associated with a lower weight gain.

A study subsequent to the systematic review (n=11,115; followed-up for 12 years) observed leisure-time physical activity to be inversely associated, and physical activity at work positively associated, with BMI, especially in women.

Children and adolescents

The Molnar and Livingstone systematic review identified two prospective studies that investigated the influence of self-reported physical activity on the change in relative body mass index. In a cohort of 146 preschool children, followed-up over a 3-year period, increases in children's leisure activity at follow-up were associated with decreases in subsequent weight gain. In a cohort of 112 prepubertal children, followed up for 4 years, the amount of physical activity at baseline was not associated with BMI variance at follow-up.

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, 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. The other six studies found an inverse association between higher levels of physical activity and weight gain or a positive association with sedentary activities.

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

The National Heart Lung and Blood Institute's Growth and Health Study of 1,152 black and 1,135 white girls followed up from ages 9 or 10 to 18 or 19 years reported physical activity levels of girls during adolescence significantly affected changes in BMI and adiposity. It was concluded preventing the decline in activity observed during adolescence might be an

important method to reduce obesity.

In a study of 208 children followed-up for a median of five years, physical activity was inversely related to fat mass development in boys and but not in girls . A prospective comparison (5 year follow-up) of children (n=2,727) from different schools in the UK, observed that boys in schools providing 3 weekly physical education sessions had smaller increases in fat mass than boys in schools providing one or two sessions. Differences in girls were in the same direction, but not significant; There were no differences in BMI changes or the percentage of students classified as obese between schools of higher and lower frequency of physical education .

The tracking of physical activity from youth to adulthood and risk of weight gain

Awaiting papers for this section

Summary

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

It is likely that imprecise measurement of activity exposures weakens the observed relationships . 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 of limited value in determining fat and lean tissue mass across the normal range in adults and children .

Physical activity is not easy to assess because it is a complex multi-dimensional behaviour and takes place in a variety of different domains, i.e. in transportation, domestic life, occupation and recreation . In addition, physical activity assessment needs to consider intensity, frequency, duration and the type of activity undertaken .

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 total energy expenditure . Although subjective measures of physical activity have proved sufficient to demonstrate inverse associations with many health outcome, they have infrequently separated physical activity into its different dimensions and they have not allowed the estimation of dose-response effects . The use of objective measures of physical activity is required to elucidate the dose-response relationship between physical activity and health, as well as, for determining current levels of physical activity, monitoring compliance with physical activity guidelines and determining the effectiveness of intervention programmes designed to improve physical activity.

Prospective studies of objectively measured physical activity and weight gain

Objective measures of physical activity

As noted above cardiorespiratory fitness had been used as a surrogate for physical activity, but this does not define the amounts and types of physical activity or the amount of energy expenditure. In children, furthermore, there is only a weak association between

cardiorespiratory fitness and the level of physical activity .

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, however, does not give day-to-day information nor does it give information on the forms, frequency and intensity of physical activity undertaken .

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. The HRM method is limited in its ability to differentiate between modest increases in 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 . PAEE can be estimated in groups using HRM and accelerometry, but the DLW method provides a more accurate assessment.

Adults

A study in healthy middle aged adults (n=5223), followed up for an average of 7.5 years, observed that increased cardiorespiratory fitness was associated with an attenuation in weight gain. In a study of 459 adults, followed-up for 15-20 years, a lower risk of obesity was observed in those with higher cardiorespiratory fitness at baseline, but the association was weak .

No relevant studies were identified in the Fogelholm and Kukkonen-Harjula (2000) systematic review, but the Wareham *et al* (2005) systematic review identified two studies. In Pima Indians (n=92) PAEE, as determined by DLW technique, was not associated with change in body weight during follow-up after 4 years . 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 4 year follow-up was investigated . PAEE predicted change in FM in younger adults, but not older adults, although the effect size was small. Younger adults on average gained weight during the study. In older adults, who were on average weight stable, PAEE predicted gain in body weight (an increase in FM and FFM).

A later study of obese (n=13) and normal weight (n=15) young adults followed-up for 4 years assessed RMR, substrate oxidation, movement economy (ml O₂ kg⁻¹ min⁻¹), aerobic fitness, total 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 (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 obesity status.

Children and adolescents

The Molnar and Livingstone systematic review identified five prospective studies that investigated the influence of objectively measured physical activity on the change in relative body mass index.

A study of 32 active and 32 non-active boys followed longitudinally from 13 to 18 years of

age used a physical fitness test battery to assess physical activity found no association between physical activity and growth in somatic dimensions, including adiposity (skinfolds). The Framingham Children's Study (106 children aged 3-5 years followed-up till first grade) found children with low levels of physical activity (assessed using electronic motion sensor) gained substantially more subcutaneous fat than did more active children .

Three studies had used DLW techniques. A study of infants of 6 lean and 12 overweight mothers observed reduced TEE, and particularly PAEE, at 3 months was associated with weight gain during the first year of life in infants born to overweight mothers . A subsequent study in infants (n=33) born to non-obese mothers, found no association between TEE at 3 months with indices of body fatness at 9 and 24 months of age .

A study of 75 children aged 3.5–7.0 years and followed-up over 4 years found no association between TEE or PAEE and change in percentage FM, adjusted for fat-free mass . It has been suggested that measurement error and adjustment of data could have obscured any differences that may have existed in this study .

The Wareham *et al* (2005) systematic review 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.

One study in 103 children assessed physical activity using accelerometry and observed children in the highest tertile of average daily activity from ages 4 to 11 years had consistently smaller gains in BMI, triceps, and sum of five skinfolds throughout childhood .

The other studies used DLW techniques. A study in 47 girls observed an inverse association between PAEE adjusted for FFM and percentage FM at a follow-up of 1.6 years, but not at 2.7 years . One study in 88 girls observed a small positive relationship between TEE, but none for PAEE, adjusted for baseline weight and percentage FM at a follow-up for 2 years . Another study in 95 children followed-up for 3-5 years observed no association between RMR, TEE or PAEE, adjusting for initial body composition, and change in adiposity, but aerobic fitness was inversely associated with adiposity . A study in 26 infants (9-12 months) followed up at 2 years of age observed that TEE, adjusted for FFM, was not related to change in FM . It was concluded that overall the results from these studies was mixed.

Studies in overweight Pima Indian children and adults 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.

Several studies have been published since the review. A study in 196 pre-menarcheal girls followed up over 4 years found no association of PAEE (or other EE variables determined by DLW techniques) with relative weight and percentage FM during adolescence .

A study in a triethnic cohort of 3-4 year old children followed for 3 years, observed physical activity (as assessed by heart rate monitoring) to be positively associated with BMI in year 1, and negatively associated in years 2 and 3, with a stronger negative relationship in year 3 than 2 .

A study in 879 children and adolescents (aged 5-18) followed-up after 1 year, assessed physical activity using accelerometry . The percentage of time in sedentary activity was

positively associated with weight gain and the percentage of time in light activity was negatively associated. The percentage of time in moderate and vigorous activity was not associated with weight gain.

Summary

Overall, the results from prospective studies in children, adolescences and adults were mixed and the associations identified were generally of small magnitude .

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 . 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 . The use of DLW measures of PAEE to identify how much physical activity 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 heart rate monitoring and accelerometry is also required .

The potential impact of exercise intensity on change in BW and FM remains unclear 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

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

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.

This systematic review was subsequently updated with a further seventeen trials in 2005 . 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 were differences in body composition between intervention and control group were observed, two found an increase in body weight in the control group, but weight stability in the intervention group , one found a weight reduction in the intervention group and the other, decreases in both groups . Two trials observed no effect on weight gain

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, with two of them reporting effects in boys only. The other eight trials reported no significant effects on body weight or composition at follow-up.

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 is effective.

A cluster randomised controlled single blinded trial over 12 months in 545 preschool children (average age 4.2 years) using nursery and home-based intervention was found not to reduce body mass index at follow-up.

A randomized trial of paediatric weight management, compared an intensive family-supervised exercise based program involving, nutrition education, and behavioural modification with traditional clinical weight management counselling. Overweight children (n=119) in the family-based program had less weight gain, lower body mass index, less body fat and greater improvements in insulin sensitivity than children who received traditional weight management counselling through 12 months of follow-up.

Physical activity and energy intake

It has long since been hypothesized that the mechanisms controlling energy balance may be accurate in persons with higher levels of physical activity, but that in sedentary persons there is a threshold of physical activity below which these mechanisms become imprecise and that this leads to obesity. At low levels of energy balance this dysregulation would lead to a positive energy balance. There is some evidence that the coupling between energy expenditure and energy intake may be less at low levels of physical activity.

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.

There appears to be a spontaneous reduction in hunger associated with participation in exercise programmes. 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. 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. Reducing levels of physical activity was observed not to result in a compensatory reduction of energy intake, leading to a positive energy balance, in lean men over 7 days.

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 .

Longer term studies are required to quantify this relationship and address why long term physical activity interventions to induce weight loss appear to have relatively little effect .

Relationship of physical activity intensity to PAL and TEE

The application of accelerometry concurrent with DLW measurements has been used to define physical activity intensity as a determinant of the TEE and PAL. Physical activities can be defined into various categories, e.g. low, representing lying, sitting and standing, moderate including walking and high, including household activities, exercise and sports. Other classifications include time spent sedentary, light, moderate and vigorous intensity physical activity.

In young adults, within the normal physical activity range, the distribution of time spent at activities with low and moderate intensity determined the PAL. High-intensity activity was not observed to have much impact on daily energy expenditure. In children, an inverse relationship with time spent in low-intensity activities and a positive relationship with time spent in high-intensity activities has been observed , while in an elderly population a shift to spending more time in low-intensity activities instead of moderate- and high-intensity activities .

A study of children in Scotland, also observed that time spent sedentary was inversely correlated with PAL, but found time spent in light-intensity activity, and not moderate- and vigorous -intensity activity, was positively correlated with PAL .

Overall, this suggests reducing sedentary behaviour and increasing light- and moderate-intensity activities (rather than vigorous-intensity activity) increase PAEE.

In a case control study, obese adolescents (n=18) were observed to have the same energy expenditure (as measured by DLW techniques and adjusted for FFM) as matched controls (n=18), but had lower levels of physical activity (as measured by accelerometry) than controls . Everyday physical activity of moderate intensity was observed to be lower in the obese group. The increased energy cost of moving a larger body mass may explain why the obese group, despite having the same energy expenditure adjusted for body composition, were less active than the control group. It was concluded that physical activity was not necessarily equivalent to the energy costs of activity.

Defining the amount of physical activity required to maintain energy balance

The issue of how much physical activity is required to prevent unhealthy weight gain is very complicated, and more data are necessary for a definitive conclusion . The energy expended in physical activity may not be the same as the amount of physical activity required to prevent excess weight gain. The intensity of physical activity may be more relevant than the total amount of physical activity . The application of objective techniques is required to define the dose-response relationship between PAEE, the duration, frequency and intensity of physical activities and subsequent weight gain.

Despite this lack of definitive data, and in the light of the increasing adiposity of the many

populations, responsible public health recommendations have been made using the available evidence . The UK recommendation is for moderate-intensity physical activity of approximately 45-60 minutes per day to prevent the transition to overweight or obesity. People who have been obese and who have lost weight may need to do 60-90 minutes of activity a day in order to maintain their weight loss.

Survey data show, however, that only about a third of the adult UK population meet the general physical activity recommendation to have at least 30 minutes a day of moderate intensity physical activity, let alone 45-60 minutes five times a week.

Several studies have compiled datasets of DLW measures of energy expenditure to examine the relationship between energy expenditure and body fatness . These studies found that in males there was an inverse cross-sectional relationship between PAEE and percentage body fat, but in females no such relationship was apparent.

In the US, datasets of DLW measures of energy expenditure were employed by the Institute of Medicine to define physical activity recommendations to maintain energy balance . Adults maintaining a BMI within the healthy range (18.5-25.0 kg/m²) were observed to have a mean PAL of 1.7, which was estimated to be the equivalent of 60min or more of moderate intensity physical activity a day. On the basis of the DLW data and results from epidemiological studies, the physical activity recommendation for adults to maintain weight balance in a normal range was 60min or more of moderate intensity physical activity a day. The recommendation for children was for a minimum of 60min or more of moderate intensity physical activity a day

It has been suggested, however, that this approach to define how much activity is required to prevent unhealthy weight gain is inappropriate , because the data were cross-sectional and the differences in PAL levels between normal weight and overweight/ obese individuals within the DLW dataset were very small.

When comparing PAL values between normal weight, overweight and obese groups it is assumed that by adjusting for RMR the potential influence of body weight and composition is removed. Although this assumption may be valid for sedentary or low-intensity activities, PAL is not necessarily independent of body weight or FFM , particularly in weight bearing activities of moderate to vigorous intensity. In such instances a heavier individual may have a higher PAL as a result of their larger weight . Comparisons of PAL values between lean and obese subjects may not, therefore, be valid. The Institute of Medicine report did not make any dietary or physical activity recommendations for overweight or obese individuals.

This highlights the issue of whether a recommendation for physical activity based on energy expenditure data in normal weight individuals would be applicable to overweight or obese individuals, and whether it could be translated into specific physical activities.

Issues to address

- To determine the descriptive level of physical activity in the UK population. The NDNS appears to overestimate. The previous DRV report used the sum of energy costs of specific activities performed over short periods for various work and leisure activities. Average levels of energy expenditure in different age and sex groups could be derived from the DLW dataset.

- To determine the prescriptive level of physical activity, presumably based on energy balance, in the UK population. Should this be derived from the DLW dataset for normal weight subjects? Should it be extrapolated from the physical activity recommendations? Is the evidence sufficient to define a level of physical activity associated with energy balance?

References