

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

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Summary

The current guidelines for physical activity are based on the prevention of cardiovascular disease. In this article the magnitude and type of physical activity required to prevent unhealthy weight gain are assessed. Five categories of analyses are considered, ranging from the most rigorous analyses (based on D_2O^{18} measures of energy expenditure) to socio-ecological associations. To standardize the approach, published work on the extent of exercise was expressed as a physical activity level (PAL), i.e. the ratio of total expenditure to the measured or estimated basal metabolic rate. D_2O^{18} , direct monitoring and measurements of activity patterns and detailed prospective studies of substantial population groups all suggest that a PAL of ≥ 1.8 is required to limit the proportion of overweight and obese adult men. Data on women are more difficult to interpret because women are less active and the relationship with physical activity is usually less clear. Post-obese women with a PAL of >1.75 do not regain weight and other data are consistent with the need for a PAL of ≥ 1.8 . The analyses in both sexes are based predominantly on adults living in a Western society with the ready availability of energy-dense foods. Vigorous activity is more clearly linked to weight stability, allows a higher intensity of exercise for general activities and shortens the time needed for achieving a PAL of 1.8. This activity level is equivalent to an additional 60–90 min of brisk walking in adults who normally undertake only modest exercise. These demands are greater than the current suggested levels for cardiovascular benefit and imply the need for different environmental policies, rather than health education policies, if societies are to become generally more active and avoid unhealthy weight gain.

Keywords: Obesity, physical activity guidelines, physical activity, unhealthy weight gain.

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Introduction

In this article we examine whether the activity guidelines are also appropriate for preventing unhealthy weight gain and obesity. In addition, we assess the extent to which the issue of weight maintenance influenced the original analyses in relation to cardiovascular disease gain.

The original review exploring the interactions of exercise and body weight considered weight as not a serious issue (1). Later, the 1996 National Institutes of Health (NIH) Consensus Panel (2), which influenced the official report from the US Surgeon General on Physical Activity and Health, did consider unhealthy weight gain and obesity as risk factors in cardiovascular disease and the lack of

progress in reducing obesity rates. They also commented on the alarming rise in childhood obesity and its role in promoting cardiovascular disease in adulthood, and noted an inverse relationship between physical activity and body fat – especially visceral fat. However, the Panel did not address the issue of what impact, if any, their switch to the moderate guidelines would have in preventing unhealthy weight gain and its impact on heart disease. Furthermore, it did not question whether the kilocalories expended from the new exercise prescription would be adequate to boost the energy expenditure of sedentary individuals to a level that would be sufficient to balance their probable energy intake.

The US Surgeon General's 1996 voluminous report on Physical Activity and Health (3) noted that around 60% of Americans were sedentary and undertook very little recreational physical activity. Again, heart health remained the primary focus. Relatively little attention was paid to the relationship between physical activity, the prevention of unhealthy weight gain, the escalating obesity rates in children and adults, and their association with type 2 diabetes and cardiovascular disease. The Surgeon General's report noted that it was 'commonly believed' that physically active people were less likely to gain weight over the course of their lives and that low levels of physical activity were a cause of obesity. The report, however, acknowledged that there was a paucity of data to evaluate the truth of these suppositions but it accepted that several cross-sectional studies had shown 'lower weight, body mass index (BMI) or skin-fold measures among people with higher fitness levels of self-reported physical activity or fitness' but prospective studies had shown less consistent results.

In June 1997, an Expert Consultation on obesity, with substantial contributions from the International Obesity Task Force, considered the role of physical activity in the prevention of obesity and was very similar in its conclusions to the US Surgeon General's report. It quoted the US analyses as suggesting that 'low intensity, prolonged physical activity such as purposeful walking for 30–60 min almost every day can substantially increase energy expenditure, thus reducing body weight and fat' (4).

While the World Health Organization (WHO) report effectively adopted the new moderate activity guidelines – and indeed even stressed the benefits of low-intensity activities – it did not attempt to show how much extra energy expenditure would be necessary to increase the physical activity levels of sedentary and moderately active individuals to a target level where energy balance would probably be achieved and obesity avoided. It recommended further research to allow 'quantification of the amount of voluntary energy expenditure necessary to prevent weight gain in adults in sedentary occupations'.

In 1998, the US NIH National Heart, Lung and Blood Institute published its own evidence report on overweight and obesity in adults, based on a detailed review of the

current literature (5). The role of physical activity in weight management was given particular consideration and concluded that all adults should set a long-term goal to accumulate at least 30 min, or more, of moderate-intensity physical activity on most, and preferably on all, days of the week. However, it did not consider whether the recommended volume of energy expenditure (approximately 1000 kcal per week) would be sufficient to prevent unhealthy weight gain for most American adults.

In December 2001, the first national action plan for preventing and decreasing overweight and obesity in the US was published by the Surgeon General (6). The report outlined strategies that communities can adopt in order to combat the increasing prevalence of overweight and obesity in children, adolescents and adults across the nation. The report emphasized the need to continue to adhere to the Federal physical activity recommendations of 30 min of brisk walking on five or more days per week.

Analytical strategy for reassessing the physical activity needed to prevent weight gain

Given these coherent conclusions from a series of expert research, United Nations (UN) and National policy groups, any re-evaluation of their conclusions might be seen as premature. However, in this appraisal a distinction is made between the quality of the techniques used to evaluate physical activity, and a particular emphasis is placed on the quantitative measures of energy expenditure. The different approaches to the assessment of physical activity can be considered to be of five types, as follows:

(1) The most accurate measurements of total energy expenditure over a 1–2-week period can be achieved with the use of double isotopically labelled water (D_2O^{18}). It has been increasingly recognized that the D_2O^{18} methodology, now that the mass spectrometric techniques and the mathematical formulae have been resolved, provides the most accurate estimates (7,8), but the prohibitive costs of this isotope, together with the analytical equipment and expertise that are needed to perform the measurements, limit its general application to epidemiological studies.

(2) The next most accurate method involves the direct monitoring or self-recording of the minute-by-minute types of activity throughout the day with direct or inferred measures of the individual costs of the activities.

(3) The third direct monitoring technique involves measurements of activity with various types of pedometer or tachometer, which then are converted into energy units by reference to tables or preferably by direct calibration measures. An allied approach is the use of treadmill testing as a way of investigating the physiological impact of exercise intensity where the individual's treadmill capacity is used to infer the prevailing intensity of their physical activity.

(4) The fourth general approach, giving less reliable measures, involves the use of questionnaires on different forms of activity at work, travelling to and from work, and activity in the so-called leisure hours. Prospective studies, and particularly those which assess the impact of reported changes in physical activity specified in detail on body weight changes in large numbers of adults monitored over a number of years, for example between 5 and 10 years, are most valuable. Cross-sectional studies are less helpful, especially if only limited indices of activity are used.

(5) Finally, crude societal indices of individual or group activity such as the ownership of cars, television sets, etc., may be used to relate group or population prevalence rates of obesity.

One of the major problems with these studies is the difficulty in establishing the validity of the activity measurements. The field of physical activity and health is expanding with methods that usually differentiate between different grades or intensities of activities but give little indication of the implications for the total daily energy turnover. We have therefore estimated the physical activity level (PAL) values from our original FAO/WHO/UNU (9) analyses, which were not based on questionnaires but on the second category of quality measurements, i.e. direct monitoring of minute-by-minute activity and direct measurement of the cost of these activities. In the original calculations of the energy cost of specific activities, it was found that these could be expressed for men and women of different body weights in a uniform way as a multiple of the basal metabolic rate (BMR) (10). These values were later expressed as METs (work metabolic rate/resting metabolic rate) by those involved in physical activity research. Women, however, have overall PALs, which are lower because they either limit the intensity of their activities or have longer pauses between exercise episodes. This gender difference

was clearly recognized in the FAO/WHO/UNU 1985 report (9) and observed by Ferro-Luzzi & Martino (11) in their analyses. Similar conclusions were drawn by Black *et al.* (7) from their collation of D_2O^{18} studies. Black *et al.* (7) also noted that the FAO/WHO/UNU 1985 analyses seemed appropriate, but that the UK Department of Health PAL values for occupational and leisure activities, which had been adjusted based on perceived and reported levels of activity, were somewhat low, particularly at the higher activity levels. Black *et al.* found from their D_2O^{18} analyses that PALs were $\approx 11\%$ lower in women than men; therefore, in deriving estimated PALs for similar activities, we have reduced the men's values by 0.1 to provide reasonable estimates of the PAL of women, as used in the report of the UK Department of Health (12).

A somewhat different approach involves clinical studies on obese or post-obese adults who, by definition, have proved more susceptible to weight gain. Only limited reference will be made to these studies because the current analysis deals with the primary prevention of unhealthy weight gain in the population

Results

Assessment of physical activity needs associated with normal BMIs using the most accurate D_2O^{18} techniques

Several studies are available relating body weight (or fat composition) to estimates of physical activity from the difference between D_2O^{18} total energy expenditure measurements and BMR. The first, by Schoeller, the pioneer of D_2O^{18} studies in humans (13), is shown in Fig. 1 and is based on the collation, by Schutz & Shoeller, of data from 299 individuals (126 men and 173 women) obtained in 22 studies from developed and developing countries with a

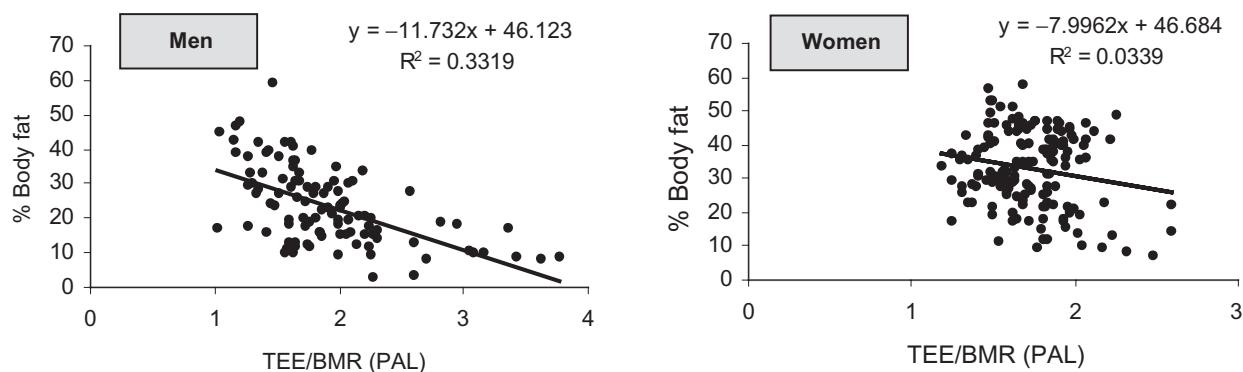


Figure 1 Relationship between body fat and non-basal energy expenditure. Relationship between body fat and the ratio of total daily energy expenditure (TEE) to basal metabolic rate (BMR) from 22 D_2O^{18} studies comprising men (126 subjects) and women (173 subjects) for whom BMR data were available. When compared by quartile of TEE/BMR, body fat content increased significantly ($P < 0.05$) with decreasing TEE/BMR. The relationship was not significant for women. The data were originally presented by Schulz & Schoeller (14).

bias towards the obese in developed countries. There were few observations on very active women with PAL values of >1.95 . There was a statistically significant ($P < 0.01$) inverse relationship between the body fat content of men and women and the PAL, defined as the ratio of total expenditure (estimated using the D_2O^{18} technique) to the BMR, if the data from both sexes were combined. Separate analyses, based on data kindly supplied by Schoeller (Fig. 1) showed only a statistically significant relationship in the men. The issue then was how to relate the % body fat to the upper limit of the designated normal BMI value, i.e. 25 kg m^{-2} . Note that the studies used different measurement techniques for body composition, but Schoeller had ensured that earlier errors in the D_2O^{18} technique of others were not an issue in this relationship.

Specifying the relationship between BMI and body fat has recently been considered by Gallagher *et al.* (15), who used the four-compartmental model or dual-energy X-ray absorptiometry (DEXA) method for predicting body fat. As the WHO derivation of 'normal' BMI values was largely based on US and European studies of mortality and morbidity in Caucasians, we used the measurements obtained by Gallagher *et al.* in equivalent groups. Again, as expected, there were age differences in the BMI-% body fat relationships. Taking the mean age of subjects in the study of Schulz & Schoeller (14) of 32 ± 14 years (men) and 35 ± 10 years (women), which excludes athletes, Pima Indians and those from developing countries, the Gallagher equations predicted an upper normal limit of % body fat for white and African-American subjects of 19.9% in men and 33.4% in women [values at BMI 18.5 and 25.0, respectively, were 8.5% and 19.9% (men) and 21.4% and 33.4% (women)]. On this basis, the data in Fig. 1 might suggest that PALs of 2.24 and 1.66 are the levels appropriate for maintaining BMI values of 25 kg m^{-2} in men and women, respectively, but the range of PALs is limited, particularly in the women who had a mean BMI as high as 27.0.

A similar collation subsequently became available from Westerterp & Goran (16), who also considered 22 studies from which they extracted data on 54 men and 40 women 18–49 years of age. In each study their energy expenditure had been measured by D_2O^{18} and the individuals had a wide range of BMI values, i.e. $20\text{--}35 \text{ kg m}^{-2}$. Figure 2 reproduces the data where it becomes evident that a clear inverse relationship between body fat and non-basal energy expenditure (NBEE) is again found in the men, but not in the women. The men on average had a mean PAL of 1.74, a BMI of 24.2 kg m^{-2} and a body fat content of 21%. The data in Fig. 2 suggest that to have only very few men with a body fat content of $>20\%$ requires an additional non-basal energy expenditure of $>1.5 \text{ MJ d}^{-1}$ above the mean, which is equivalent in this group to a PAL of approximately 1.9–2.0. Converting the NBEE values into $\text{MJ kg}^{-1} \text{ d}^{-1}$ to

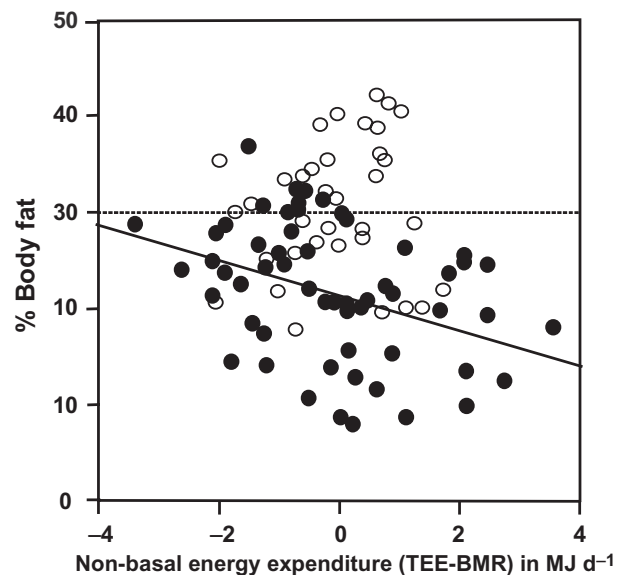


Figure 2 Relationship between % body fat and physical activity in men and women [reproduced from Westerterp & Goran (16)]. Subjects were healthy men and women (18–49 years of age) whose energy expenditure was established by the double-labelled water method, with the physical activity component calculated after measurement of basal metabolic rate. They were a subsample (from 22 studies) where at least 10 subjects for each gender were measured. Body mass index (BMI) values ranged from 20 to 35 kg m^{-2} . The graph shows a significant ($P < 0.01$), inverse relationship between % body fat and non-basal energy expenditure in men, but not in women (upper line). The data were reproduced with permission of the International Journal of Obesity © Nature Publishing Group.

make them comparable to the Schoeller data, leads to similar conclusions. For women, the PAL range was much more limited with no evidence of women having a high activity or PAL level.

Schoeller (8) then reviewed the problem of weight gain in relation to physical activity in more detail, having highlighted the problem that the D_2O^{18} technique, when first introduced into human studies, had led to discrepant results in different hands. Using his own data and a standard D_2O^{18} measurement technique he reaffirmed the statistically significant ($P < 0.05$) inverse relationship between BMI and PALs of data with the sexes combined. Men with PALs of 1.66–1.90, classified as 'moderately active', had a mean BMI value of 25.5 kg m^{-2} and, in subgroup analyses, did not gain weight. Women, however, seemed to need to undertake activity of a 'heavy' nature (equivalent to a PAL of 1.76–2.06) before their BMI values were maintained at 27 kg m^{-2} . Schoeller highlighted the possibility of a gender-based difference in the response to exercise, as shown in some studies of rodents. When Schoeller then applied an estimate of the PAL from intake and the estimates of BMR, the threshold PAL for limiting the prevalence of overweight was 1.8.

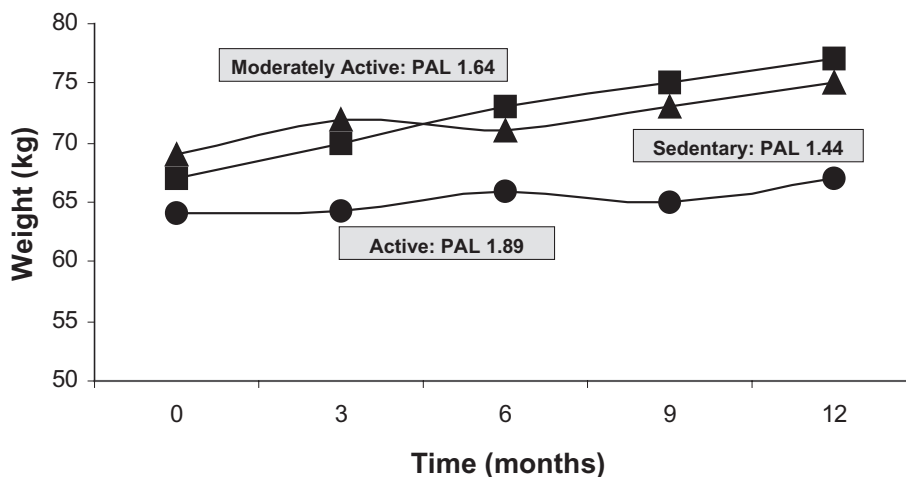


Figure 3 Relationship of physical activity level (PAL) to weight regain in previously obese women. Data were taken from Schoeller *et al.* (17). Subjects were 33 previously obese American women (one of the original 34 dropped out of the study), 20–50 years of age. Their PALs were determined by the double-labelled water method and are as follows: active group, 1.89 ± 0.08 ; moderately active group, 1.64 ± 0.05 ; sedentary group, 1.44 ± 0.08 . The mean body weights of the three groups in the year after completion of weight loss are shown. Time–group interaction, analysis of variance (ANOVA), and post hoc *t*-testing indicated that increases in weight were lower in active women ($PAL > 1.75$). The data were reproduced with permission of the American Journal of Clinical Nutrition © Am J Clin. Nutr. American Society for Clinical Nutrition.

Direct measurements of physical activity in post-obese and weight-regain subjects

Schoeller *et al.* (17) also conducted studies with D_2O^{18} on American women aged 20–50 years of age who had lost weight and were then monitored for their weight change over the subsequent year. Their data are shown in Fig. 3, where it is evident that moderately active women with PALs of 1.64 ± 0.8 gained the most weight and only those with PALs of >1.75 had statistically significantly less weight gain. Very little weight increase occurred in those with PALs of 1.89 ± 0.08 . Furthermore, the weight gain in women with PALs of 1.69 could be arrested if they increased their activity to a PAL level of 1.75.

Directly measured cross-sectional analyses of physical activity

Another major analysis of total expenditure measured by diaries and direct measurement of energy costs, i.e. conforming with the second investigation category outlined above and involving the most rigorous methods of measurement prior to the advent of D_2O^{18} , comes from Ferro-Luzzi & Martino (11) who had undertaken the first systematic assessment of physical activity needs for the avoidance of obesity for the Ciba Conference held in Jamaica in November 1995. Ferro-Luzzi re-examined a global database of 1550 subjects in 55 separate studies, deliberately excluding data on athletes. Figure 4 shows a clear relationship between physical activity in men and their BMI values, but again no such relationship is found

in women. However, all the BMI groups were active at PAL values which would conform with current cardiovascular, US Surgeon General and obesity-related WHO guidelines. Clearly, a PAL of 1.7 was associated with overweight in the men, whereas PAL values of ≥ 1.8 were associated with a normal weight. Ferro-Luzzi also assessed the odds ratio of being overweight at different PALs. Only when PALs were >1.8 in the men was the odds ratio of avoiding being overweight statistically different from zero (7.6; CI: 4.4, 13.3).

Preliminary conclusions from the most accurate estimates of physical activity

From these two different approaches to the assessment of physical activity it seems reasonable to conclude that higher weights in adults throughout the world occur when PALs are between values of 1.55 and 1.7, i.e. within a range that would conform with current cardiovascular disease guidelines. It is also clear that weight gain is less likely if PALs are ≥ 1.8 . Women – from both developing and developed countries – seem to be not only less likely to engage in activities requiring a high level of energy expenditure, a feature originally recognized in our analyses of international data for the FAO/WHO/UNU report (9), but they also appear to be more susceptible to much higher than normal body fat levels at PALs equivalent to those found in men. Schoeller's post-obese data (Fig. 3) suggest, however, that in women who are attempting in an affluent society to prevent weight regain and are therefore presumably particularly diet conscious, a PAL of 1.8 is again required to limit unhealthy weight gain.

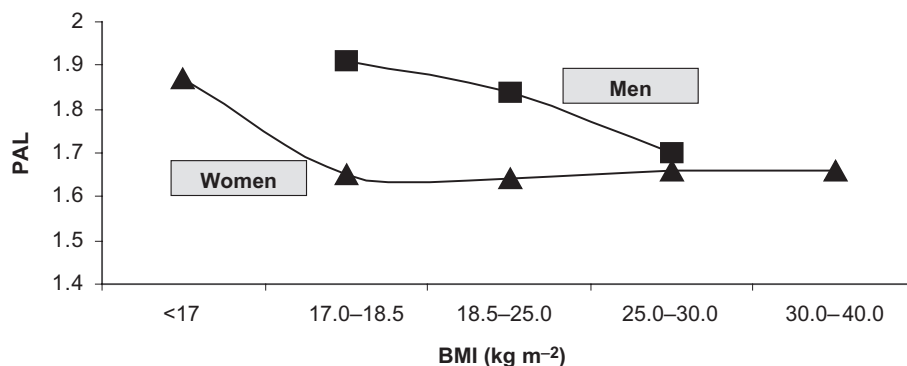


Figure 4 Mean physical activity level (PAL) by gender and body mass index (BMI). Data were taken from Ferro-Luzzi & Martino (11). Subjects were 611 men and 693 women who represented a selected subset of worldwide data (55 separate studies, 1550 individuals studied in more than 20 countries). Athletes were specifically excluded. The PAL is given as a mean value. Number of subjects in each BMI category (< 17.0, 17.0–18.5, 18.5–25.0, 25.0–30.0, 30.0–40.0), respectively, were for men: 0, 26, 491, 94, 0; and for women: 9, 76, 449, 103, 56.

Less direct measures of the energy value of physical activity: prospective studies based on treadmill or pedometer testing

We are not aware of published data on population groups with measures of activity by pedometer or tachometer in relation to BMI, although extensive data exist in Japanese population studies conducted by the Japanese Government. In the absence of these data the most coherent major data sets come from DiPietro *et al.* (18), who carefully measured the aerobic fitness as a surrogate for physical activity in more than 4500 men and >700 women who received three examinations between 1970 and 1994 with a mean follow-up of 7.5 years. Each 1-min improvement in treadmill time over the years reduced the odds of a weight gain of >5 kg by 14% in men and by 9% in women. There was no overall association between this index of intense physical activity and actual weight loss, and it was concluded that physical activity, inferred from the fitness tests, plays more of a role in attenuating age-related weight gain and preventing significant weight gain, rather than in promoting weight loss. DiPietro *et al.* also suggested that increasing amounts of physical activity may be necessary to maintain effectively a constant weight with increasing age. These studies are of great value in deriving objective and reproducible measures of physiological fitness. This value provides a good index of the individual's habitual intensity of exercise fitness, but at best gives only a crude indication of the total energy expended in physical activity.

Analyses based on questionnaires: prospective studies

In an excellent detailed systematic review, Fogelholm & Kukkonen-Harjula (19) dealt with 16 prospective studies relating physical activity to weight gain. Fogelholm's table

has been updated in relation to new analyses of body weight, physical activity and cancers (20). In addition to Fogelholm's collation, there have been previous large studies, e.g. by Morris and Paffenbarger's groups, together with more recent analyses. Table 1 sets out those studies where it is possible to estimate from the specific MET values listed, or from a general description of activity, the probable PAL equivalents of the activities specified. On the basis of the PAL estimates in Table 1, it is clear that men need sustained and often vigorous activity (equivalent to PALs of ≈ 1.8 or more) to maintain their body weight. To argue that the PAL values should be lower is difficult given the evidence of the more direct analyses of METs in these studies and the observed distributions of PALs in the D₂O¹⁸ analyses. Those studies with larger numbers of subjects and longer follow-up periods prove most rewarding. Thus, the study of Williamson *et al.* (23) showed a clear maintenance of weight only at the highest activity levels monitored during the baseline studies, these activity levels reasonably amounting to a PAL of ≈ 1.8 . Similarly, the data of Weir *et al.* (32) clearly show data which, contrary to the authors' evaluation, reveal that average weight gains of 0.5 kg annum⁻¹ occurred at PALs of ≈ 1.65 in men, and a higher PAL (of ≈ 1.8) was needed for weight maintenance in the young adults who, in the whole group, were gaining weight progressively. Similarly, a study by Rissanen *et al.* (22), which was omitted from the Surgeon General's 1996 analyses, reveals the importance of substantial activity before weight maintenance is evident.

Two of the publications included in Table 1 deserve particular mention. The first, by Haapenän *et al.* (28), dealt with a 10-year follow-up of 5000 men and women. They found an association between baseline levels of leisure-time physical activity and subsequent increase in weight only in women, but, more importantly, they observed that vigorous activity was particularly protective in terms of weight

Table 1 Physical activity (PA) and weight gain (WG): a summary of prospective studies with physical activity level (PAL) estimates

Country & date of study	Subjects (gender, age at entry)	Follow-up (years)	Assessment of PA	Statistical adjustments	Main effect of PA	Statistically significant results	Estimated PAL		First author (Ref.)
							Men	Women	
US 1962-88	17 321M (mean 46 years) Harvard Alumni	12-16	Total PA by Paffenbarger questionnaire in kJ or METs	None	NS	No relationship between total or vigorous activity and BMI			Lee (21)
Finland 1966-76	6165M 6504F (25-64 years)	5.7 (median)	LTPA at follow-up (three categories frequent, occasional, rare)	Age, education, marital status, parity, smoking, alcohol, coffee, health status (no. of children in women)	+	PA at follow-up was inversely associated with WG in men and women % Prevalence of BMI >30 Men 14.2 21.4 Women 11.2 14.1 Frequent 6.7 8.0	1.5 1.4 1.65 1.55 1.8+ 1.7+		Rissanen (22)
US 1971-84	3515M 5810F (mean 47 years)	10	OA and LTPA: three categories	Age, BMI, race, education, smoking status, alcohol, physician-diagnosed health conditions, parity	+	Weight change was inversely associated with PA at follow-up. Decreased PA was associated with WG. Baseline PA was not associated with weight change BMI Men 26.1 26.4 Women 25.6 25.2 Low Moderate High 25.0 24.1 1.8+	1.6 1.5 1.7 1.6 1.8+ 1.7+		Williamson (23)
Finland 1975-81	2110M 2490F (twin pairs) (18-39 years)	6	LTPA tertiles of total METs	Age adjusted for all twins; separate analyses of gene-PA interactions	+	PA at follow-up was significantly associated with weight change in group overall BMI at follow-up Men 24.0 22.0 Women 24.0 21.8 Low PA Medium PA High PA 23.6 21.7	1.5 1.4 1.65 1.55 1.8+ 1.7+		Heitmann (24)
UK 1976-86	2250M (45-64 years)	9.33 (mean)	LTPA in four categories		+	% Subjects >27 BMI Vigorous PA 24 None 18 Residual 14 Less frequent 10 Frequent	1.6 1.7 1.8 1.9+		Morris (25)

gain compared with indices of general activity. This was more evident in men than in women. Analogous findings were also obtained by Coakley *et al.* (31) in their prospective cohort study of nearly 20 000 men. In this study, Coakley *et al.* observed a clearly protective role for vigorous activity but also displayed the importance of limiting television viewing, taken as an index of very sedentary living. Thus, both of these papers not only emphasized the importance of physical activity in limiting weight gain, but also highlighted the particular value of vigorous exertion. This issue will be discussed below.

One intriguing feature of some of these analyses is that if the MET hour values are collated, then completely unrealistic PAL values are obtained for the average individual, i.e. PALs of >2 in Wagner *et al.* (34). Other analyses and definitions of METs in the literature are either inaccurate or unrealistic (8,33,35). This demonstrates that many of the questionnaires have an arbitrary grading in their classification of relative activities and do not necessarily reflect the true total energy expenditure. Nevertheless, an overview of Table 1 shows that surprisingly high PAL levels are needed to avoid weight gain in most studies of Western society.

Table 2 shows the other types of study where no specific quantitative analyses can be made. These studies are often expressed as the differential weight changes from the usual regression of weight increases with age. Often these increments or attenuation of weight gains are related to poorly specified indices of physical activity. Nevertheless, in general, there is a reasonable inference that increasing physical activity limits weight gain, and relatively high PAL levels are probably needed to prevent any increases in body weight in adult life.

Fogelholm & Kukkonen-Harjula (19) concluded, in their overview of the prospective studies, that selecting baseline physical activity values, i.e. at the beginning of the observation period in population studies, was not particularly linked with the subsequent rate of weight gain but that follow-up indices of physical activity – or the change in physical activity – produced more consistent results, with greater physical activity being associated with less age-related weight gain. Most studies, however, were of modest duration, i.e. <2 years, and it is difficult to evaluate the activity data in quantitative terms. Nevertheless, Fogelholm & Kukkonen-Harjula estimated, primarily from the weight regain data on previously overweight or obese adults, that ≈ 2000 kcal week⁻¹ might be required to limit weight regain in studies of overweight or obese patients. These individuals are almost certainly more susceptible to weight gain than the general population.

Gender differences

Apart from the infrequency of high levels of physical activity in women, three publications do suggest that in women

there is a clear graded effect between their levels of physical activity and improved weight stability (23,33,46). Few studies, however, reveal any clear threshold PAL for maintaining body weight in women. The questionnaire studies are less reliable than the D₂O¹⁸ or Ferro-Luzzi analyses, both of which suggest that it is unusual to have many women with PAL values of 1.8. It is therefore not surprising that the relationship between physical activity and weight stability is easier to demonstrate in men than in women. It is possible that a PAL value of 1.8 in a women, e.g. equivalent to a housewife being on her feet and engaged in household or other tasks for 12 h d⁻¹ (7), is in practice the level of exertion required in a Western environment for achieving weight stability; these levels seem, however, to be relatively unusual.

More indirect approaches to physical activity evaluations in cohort studies

Since 1998, the Blair and Paffenbarger teams have continued their investigations into the complex relationships between energy volume, fitness and intensity of activity, and cardiovascular disease and all-cause mortality. Increasingly, body weight was becoming an independent variable in these equations. Blair and Paffenbarger note that to obtain a level of fitness (as measured on a treadmill) which reduces cardiovascular morbidity, is equivalent to a 6 MET h⁻¹ d⁻¹ level of activity. This level, if added to a sedentary man's activity where the PAL is 1.5, amounts to a final PAL of 1.75. Only at this level does weight stability become apparent.

Whereas Blair and colleagues found a clear association between fitness and BMI values (18,47), Paffenbarger saw no association between BMI and activity levels (21,27) (Table 1). Part of the answer may lie in measurement techniques (treadmill fitness vs. self-reported activity). However, the more illuminating answer may lie in a comparison of the cohorts. Blair and colleagues examined both men and women who could be said more accurately to reflect the American population than a cohort exclusively composed of highly educated male Harvard Alumni who displayed no association between BMI and PAL.

Cross-sectional studies based on questionnaires

Some cross-sectional studies have shown an association between lower BMI values and higher physical activity and fitness, but the problem is often the limited nature of the questionnaires. The Surgeon General's 1996 Report noted the inconsistency of cross-sectional studies relating physical activity to body weight stability. However, some cross-sectional studies emphasize the observation that in Western societies appreciably high PAL values are found in groups

Table 2 Physical activity (PA) and weight gain (WG): a summary of prospective studies with limited quantification

Country and year(s) of study	Subjects (gender, age at entry)	Follow-up (years)	Assessment of PA	Statistical adjustments	Main effect of PA	Results	First author (Ref.)
US 1964–90	3885M 841F (mean 19 years)	21	LTPA h week ⁻¹ exercise	BMI at entry, smoking, gender, depression	+	Hours exercise negatively correlated with WG	Barefoot (36)
US 1980s?	142M 152W (mean 34 years)	2	LTPA and OA score on Baecke scale annually	Baseline weight, diet, pregnancy, smoking, alcohol, family risk of obesity	+/-	Baseline LTPA predicted lower WG in women	Klesges (37)
US 1980–89	568M 668W (20–60 years)	7	LTPA h/day	Age, smoking, sex	+	Increased LTPA associated with less WG.	Taylor (38)
US 1983–87	500F (42–50 years)	3	Initial and final total PA METs week ⁻¹ from Paffenbarger questionnaire	Sex hormone use, smoking, change in menopausal status	+	Both baseline PA and subsequent increase in PA were associated with less WG	Owens (39)
US 1985–88	1100M 1096F (18–36 years)	2	LTPA and OA	Age, BMI, perception of fatness, physical fitness, education, smoking, diet, alcohol	+/-	Low baseline PA predicted weight loss but reduction in PA associated with weight gain Overweight adults lost weight if PA increased. Paper primarily focused on weight loss	Bild (40)
Finland 1985–95	442M (36–49 years) 73% former elite athletes	10	LTPA score (intensity x duration x frequency)	Age, weight at age 20, weight at entry, chronic diseases, smoking, occupational class, diet, alcohol, marital status, former sports training	+	Increased PA negatively associated with WG. No association for decreased PA, continuous high PA or continuous low and weight change	Fogelholm (41)
US 1985–96	5115M & F (18–30 years)	10	PA x 5 examinations. Focus on heavy and vigorous activities	Alcohol intake, dietary % fat, education, time elapsed, age, smoking, clinical centre	+	MET h week ⁻¹ extra needed for weight stability: Schmitz (42) F: White 4.5; Black 6.5 M: White 12.0; Black 19.6	Schmitz (42)
US 1986–92	176M 289F (mean 47 years)	4	LTPA as aerobics = Regular PA > 3 d week ⁻¹ only	Age, energy intake	NS	No association between baseline aerobic PA and subsequent weight change (tertiles)	Parker (43)
US 1990s?	228M 892F (mean 35 years)	4	LTPA score annually. Frequency total PA > 20 min week ⁻¹	Age, diet, baseline values	NS	The cumulative duration of increased PA was not significantly associated with weight loss	French (44)
US 1990s?	176M 705F (20–45 years)	3	TV watching (h d ⁻¹)	Baseline BMI, obesity prevention treatment, age, education, baseline smoking, diet (multiple regression)	NS	TV viewing at baseline, average TV viewing and change in TV viewing not associated with weight change	Crawford (45)
France & Ireland 1991–98	8865M (50–59 years)	5	Total PA over past 12 months at baseline using MOPSA questionnaire	Age, marital status, educational level, socio-occupational class, pursuit of weight control diet, alcohol and smoking habits, and physical activity at work	+	BMI, WC and ΔBMI inversely associated with PA spent getting to work and practice of high-intensity LTPA but occupational METs h week ⁻¹ (63.1) dominated going to work (2–3 METs) + LTPA (24.2 METs)	Wagner (34)

LTPA, leisure time physical activity; OA, occupational activity; M, male; F, female.

of adults with substantial prevalence rates of obesity. Therefore, Shaper & Wannamethee (48) investigated British middle-aged men in a range of health centres across Britain and found that even at high activity levels equivalent to ≥ 1.8 PAL, $\approx 50\%$ of the population was overweight with the level of obesity close to 15%. There was, however, a clear inverse relationship between the physical activity of the men and the mean BMI value and the prevalence of obesity. Similar relationships have recently been observed in a pan-European study conducted by Martinez-Gonzalez *et al.* (35), who found independent inverse relationships between the estimated total MET h week⁻¹ and the mean BMI value, % overweight and % obese in men, but not in women. Even though the MET estimates are unrealistic, of the men with the highest MET quintile (i.e. >261 MET h week⁻¹, equivalent to >35 MET h d⁻¹ and a PAL of $>2.5!$) 35% were overweight and a further 7.4% were obese. In the women there was again no relationship between physical activity and BMI but, as expected, the activity levels were lower than those found in the men.

Another representative sample – this time the NHANES III from the US (49) – allowed crude analyses of total physical activity. The data suggested that those engaged in >6 MET activities with vigorous activity more than five times weekly were in the highest of four activity categories and had the lowest obesity rates (9.0% compared with the average rates of 20% in men and 25% in women). Those with a physically demanding job were less likely to be obese and those in inactive jobs were required to be active five or more times weekly at 3–6 METs to have a reduced chance of being obese in the US. These indices of activity are consistent with probable PALs of >1.8 , but in this study no gender differences were reported.

From these and the other cross-sectional data considered by the Surgeon General's 1996 report, there seems to be a reasonably consistent story in suggesting that there is an inverse relationship between PA and weight stability, but in current US and European societies there are groups with high PAL values but with still a considerable prevalence of obesity.

Social and ecological studies

Prentice & Jebb (50) amplified the then-unpublished UK Government's conjoint Nutrition and Physical Activity Task Forces' report on the prevention of obesity (51) by assessing the importance of diet and physical activity using crude measures of inactive lifestyles and diet. They showed that there was a much closer positive association between the rise of obesity and the reported ownership of cars and televisions (proxies for inactivity) by the different social classes in Britain than there was between obesity and food consumption, although the data did not adequately reflect increasing amounts of energy-dense foods eaten out of the

home. Whilst emphasizing the relationship of obesity to a sedentary lifestyle, the analyses do not allow the degree of activity needed to avoid unhealthy weight gain to be assessed. Nor, given the marked changes in diet and eating patterns over the last few decades and the known differences in diet between social classes, is it possible to assess the interactions of diet and physical activity in determining weight gain.

Clinical studies

Clinical studies have been very adequately summarized by Fogelholm & Kukkonen-Harjula (19), who also conclude that an increase in energy expenditure of between 1500 and 2000 kcal week⁻¹, is required in women – particularly post-obese subjects – who are attempting to avoid weight gain by ancillary dietary control.

Discussion

The currently accepted modest physical activity guidelines are clearly important for limiting the morbidity and premature mortality associated with cardiovascular diseases, which are the largest contributors to disability and premature death in both the developing and developed world. This disease burden is also predicted to dominate world health burdens for the next 20 years. What is emerging, however, is increasingly robust evidence that if physical activity is considered independently of other factors, then physical activity is also an important preventive measure for avoiding unhealthy weight gain. The evidence presented in the present report suggests that higher PALs are needed for weight stability than for inducing substantial improvements in cardiovascular health.

The implications of these graded effects of exercise on health will now need to be considered in terms of international public health policies and how they may need to change. The original policy analyses on the energy requirements for maintaining health were primarily concerned with the avoidance of undernutrition and the inability of societal groups to sustain useful physical activity when food supplies were limited (9). The original sedentary energy allowance included the cost of this short and more intensive exercise at six times the BMR (10). Some, if not all, of the exercise prescription now advocated in recent cardiovascular disease (CVD) guidelines, could already be encompassed as part of the 'desirable' physical activity specified in the original 1985 FAO/WHO/UNU report. If, however, the prescription is taken as an additional activity, as is evidently intended in the guidelines of the US Surgeon General, then there is a small additional component to the PAL of those classified as undertaking light activity. The new PAL, with all the existing desirable activity allowance, and the current recommendation for

cardiovascular health of 30 min of activity undertaken five or more times per week, amounts to a PAL of ≈ 1.6 in women compared with a previous value of 1.56. Men who undertake light activity have a similar increase to a PAL of 1.59. This additional component has not, as yet, been included in WHO policies relating to energy needs, but the original analyses also specified that sufficient food should be available to allow people to engage in socially valuable work and community activity, which could not be designated as either work-related activity or the cost of household chores. These 'desirable' physical activities were incorporated into the original specification of energy needs for those men and women undertaking light activity who were considered to need an energy intake equivalent to a PAL of 1.5 in men and 1.56 in women.

On the basis of the current analyses, a greater amount of physical activity is required for weight stability. In practice, this means the equivalent of 60–90 min of brisk walking daily or, as shown by Ferro-Luzzi & Martino (11), the introduction of much more vigorous activity. It has already been shown that vigorous activity produces distinct benefits (see Paper 1 in the current issue of *Obesity Reviews*) and, in terms of weight stability, there are also advantages of including vigorous exercise where possible (see below).

Much of the debate about the policy implications of encouraging adults to increase their physical activity levels stems from a major debate over the last 10 years as to what can, in practice, be achieved. Several studies have therefore been designed to answer the question as to how adults can best achieve long-term weight stability, and these have been briefly summarized in Paper 1.

The value of high intensity activity

It is clear from the Blair analyses of physical fitness, as well as the more general epidemiological studies of Morris and Paffenbarger, set out in Paper 1, that there are considerable additional cardiovascular benefits to be derived from intense exertion with its associated physical fitness and insulin sensitivity. The recent evaluation of cancers also suggests that there may be additional preventive benefits from high activity levels (20). Nevertheless, it seems clear that in energy balance terms the key factor is the total amount of activity undertaken.

Vigorous activity could also be of benefit in weight stability terms for two reasons. It is easier to engage in higher levels of general walking and other moderate activities at higher METs if one is physically fit and, as Ferro-Luzzi & Martino (11) illustrated, the involvement in vigorous activity such as jogging or rapid cycling markedly reduces the time needed to achieve these higher levels. This implies that not only should desirable physical activity levels be raised to ensure weight stability, but in it should

also be made clear that additional benefits can come from more intense exertion. This, however, is not a matter of simply specifying the nature of the scientific evidence, but also requires that one takes account of the circumstances of different population groups globally. It is clear that, in the context of developing countries, individual advice in relation to either sustained or intense activity is unrealistic, with many population groups seeking to limit the demands for their exertion. On this basis it seems reasonable to simply specify that a PAL of ≈ 1.8 is required for minimizing weight gain in both men and women of all ages and that this can be achieved only by being active and moving on one's feet for much longer than previously considered necessary. These higher activity levels are needed for weight stability but encompass the evident improvement in cardiovascular health from more modest exercise. These high PAL values apply to populations in a Western environment where energy-dense foods are plentiful and intensively promoted. The interactions of diet and physical activity on weight stability will be considered in further IOTF analyses.

The evaluation in the present report, but set out in a more extended form, was used as the basis for the recent FAO/WHO/UNU reanalyses of energy requirements in October 2001, which in turn informed the WHO/FAO Expert Technical meeting on diet, nutrition and the prevention of chronic disease held in Geneva in January 2002. Given the acceptance by experts that these evaluations were a reasonable estimate of energy needs for weight stability, the present report is a summary of the principal arguments used for raising the PAL level needed for overall health. Clearly, there are many gaps in our understanding, but with the global obesity epidemic gathering pace, it is important to evaluate in quantitative terms what will be required by populations if preventive measures are to be undertaken. The policy implications of an optimum PAL of ≥ 1.8 are quite different from those traditionally linked to individualized health education messages and require new population strategies to change people's environments so that these become more conducive to spontaneous and sustained physical activity.

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ses have not only made an extremely valuable contribution to the present study but have also highlighted the need for further research on many aspects of this important field of investigation.

The expert panel comprised: Steve Blair (USA); Michael Booth (Australia); Claude Bouchard (USA); Anna Ferro-Luzzi, (Italy) Mikael Fogelholm, (Finland); Ken Fox, (UK); Paul Gately, (UK); Adrienne Hardman, (UK); Bill Haskell, (USA); Andrew Hills, (Australia); Mark Hargreaves, (Australia); Jerry Morris, (UK); Neville Owen, (Australia); Thomas Robinson, (USA); Dale Schoeller, (USA); Roy Shephard, (Canada); Kate Steinbeck, (Australia); Boyd Swinburn, (Australia); Ilkka Vouri, (Finland); and Klaas Westerterp (the Netherlands).

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