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PAPER

Estimated change in physical activity level (PAL) and prediction of 5-year weight change in men: the Aerobics Center Longitudinal Study

L Di Pietro[1,2]*, J Dziura[1,2] and SN Blair[3]

[1]*The John B. Pierce Laboratory, Yale University School of Medicine, New Haven, CT, USA;* [2]*Department of Epidemiology & Public Health, Yale University School of Medicine, New Haven, CT, USA; and* [3]*Centers for Integrated Health Research, Cooper Institute, Dallas, TX, USA*

OBJECTIVE: To determine the relation between the average daily physical activity level (PAL) and the trajectory of weight change in men at risk for weight gain.
DESIGN AND SETTING: Clinic-based cohort study over an average of 5 y.
SUBJECTS: Healthy men ($N = 2501$) ages 20–55 y participating in the Aerobics Center Longitudinal Study who had received at least four medical examinations at the Cooper Clinic between 1970 and 1998.
MEASUREMENTS: Daily leisure-time physical activity was reported and body weight was measured at all four examinations. The average daily PAL (METs 24 h^{-1}) was estimated from all activities, as well as from other incidental active and passive activities. Weight change over four examinations was regressed on the change in PAL between the first and third examinations.
RESULTS: Random coefficient regression modeling indicated a curvilinear slope for *weight gain* over the follow-up among those maintaining the same PAL between the first and third examinations. Weight gain was further accelerated among men who decreased their activity. A shift from a *low* PAL ($<$1.45 METs 24 h^{-1}) to a *moderate* (1.45–1.60 METs 24 h^{-1}) or *high* ($>$1.60 METs 24 h^{-1}) PAL was necessary for weight loss over time. Men with initially the lowest PAL had the greatest benefit from increasing activity.
CONCLUSIONS: Daily PAL was inversely related to weight gain in this cohort. Increasing to or maintaining a daily PAL at least 60% above the resting metabolic rate (ie, PAL $>$1.60 METs 24 h^{-1}) may be necessary to maintain body weight in middle-age and can be achieved by incorporating 45–60 min of brisk walking, gardening/yardwork, or cycling into the daily routine.
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Keywords: exercise; prevention

Introduction

The most recent NHANES (1999–2000) data suggest a continued increase in the prevalence of overweight and obesity in the United States. O*verweight* (BMI $\geq$25 kg m^{-2}) is now present in 65% of US adults, compared with 60% at the time of NHANES III (1988–1994), whereas trends in *obesity* (BMI of $\geq$30 kg m^{-2}) have demonstrated even more dramatic increases.[1] Indeed, between 1976 and 2000, *obesity* prevalence increased from 14.5% (NHANES II, 1976–1980), to 22.5% (NHANES III, 1988–1994) to 32% (NHANES, 1999–2000).[1] These surveillance data among the general US adult population are consistent with trends observed internationally.[2,3]

The sudden marked increase in obesity has been attributed to changes in lifestyle factors, since this escalating prevalence has been occurring in a constant genetic milieu.[4,5] Overweight and obesity are a consequence of a long-term positive energy balance and the relative contributions of overeating, inactivity, and metabolic aberrations are complex.[6,7] Increasing automation and labor-saving devices over the past several decades in the home, on the job, and in the community must have resulted in an ever-decreasing daily energy expenditure, although reliable population-based data are not available. Moreover, during the past 15 y there has been a marked increase in the prevalence of *passive* leisure-time activity (ie, computer use, TV/VCR viewing). A recent

***Correspondence: Dr L Di Pietro, The John B. Pierce Laboratory, Yale University School of Medicine, 290 Congress Avenue, New Haven, CT 06519, USA.**
E-mail: ldipietro@jbpierce.org
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Harris Poll (1 December, 2003) reports that the percentage of leisure time activities that involve exercise declined from 38% in 1995 to 29% in 2003 while, conversely, the percentage of sedentary leisure time activities increased from 62 to 71% during that same time period among persons living in the United States.

The amount of daily physical activity necessary to prevent overweight and obesity is an important public health concern. Indeed, there is a paucity of data that examine the role of regular physical activity on the *risk* of weight gain or obesity. What longitudinal data there are suggest that regular activity may serve more in minimizing age-related weight gain or reducing the risk of significant weight gain among the population, rather than actually promoting weight loss.[8–10] The Physical Activity Level (PAL) has become the standard method of expressing total daily energy expenditure (TEE) in multiples of the resting metabolic rate (RMR; PAL = TEE/RMR).[11] An average daily PAL of 1.75 or more (ie, an average TEE 75% above the RMR) has been recommended as necessary to prevent obesity over the lifespan.[12] This recommended level of activity is equivalent to a TEE of 2625 kcal day^{-1} for a 70 kg person of 30% body fat and a RMR of 1500 kcal day^{-1}; however, it is based on laboratory data from small numbers of previously obese subjects.[13] Thus far, the issue has not been studied at the population level.

The purpose of this analysis is to determine the longitudinal relation between daily PAL and the trajectory of weight change over 5 y in a population at risk for weight gain. We hypothesized that: (1) the daily PAL would be inversely related to weight gain over time; and (2) a daily PAL >1.60 would be necessary to maintain a steady body weight over 5 y in this same population. Accordingly, we analyzed data from a large cohort of men participating in the Aerobics Center Longitudinal Study (ACLS).

Methods

Subjects

Study participants were 2501 men, age range 25–55 y, participating in the ACLS who had received at least four comprehensive medical examinations at the Cooper Clinic in Dallas, Texas, between 1970 and 1998. This age range was chosen in order to ensure a study population at risk of weight gain. The ACLS cohort has been providing information for over 30 y on the relation between physical activity and fitness on health, function, and longevity. Medical examinations included a physical examination, a self-administered personal and family medical history, a physical activity questionnaire, a resting and exercise electrocardiogram (ECG), anthropometry, blood pressure measurements, blood chemistry analyses, and an assessment of cardiorespiratory fitness by a maximal exercise treadmill test. Several participants had more than four examinations. In these individuals, data from the first, second, third, and last examinations were selected for analysis. All participants had complete data for each of the examinations and, since health status may be an important confounder of the relation between physical activity and body weight, we only included individuals who were free of known chronic disease at each visit as determined by the following criteria: no personal history of heart attack, hypertension, stroke, or diabetes, and no resting ECG or exercise ECG abnormalities. In order to exclude those persons with possible subclinical or undetectable disease at all four examinations and to ensure valid estimates of maximal exercise capacity, only those participants who achieved at least 85% of their age-predicted maximal heart rate ($HR_{max} = 220 - \text{age (y)}$) on the treadmill exercise tests were included in the analysis. In addition, those persons whose four examinations were completed in less than 2 y were excluded since multiple clinic visits in a short period of time may be an indicator of poor health status. All examination procedures followed a manual of procedures and were administered by trained technicians. The inclusion hierarchy is presented below (Figure 1) and details of the clinical procedures and additional exclusion criteria are described elsewhere.[14]

Height and body weight

Height (cm) and undressed body weight (kg) were measured on a stadiometer and balance beam scale at four time points over the follow-up period.

Physical activity

We assessed leisure-time physical activity (LTPA) from a series of questions regarding participation in 10 specific

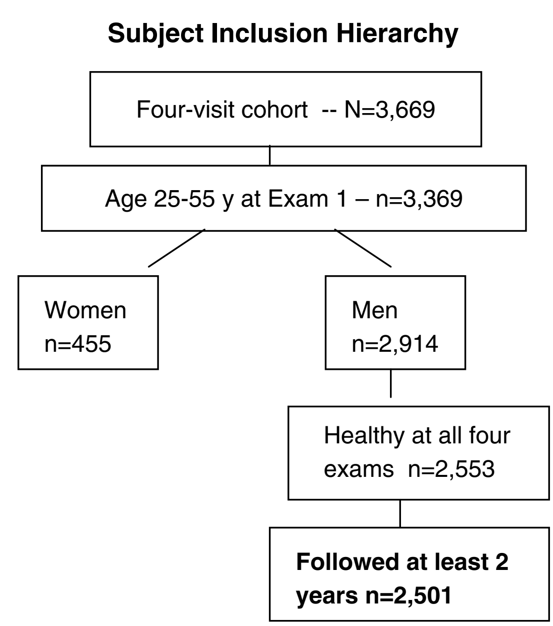

Figure 1 Subject inclusion hierarchy.

exercise-related activities within the previous 3 months. Participants were asked to quantify the frequency (times week^{-1}) and duration (min session^{-1}) of their participation in activities such as walking, jogging, treadmill exercise, cycling, swimming, racquet sports, aerobic dance, and other sport-related activities (eg, soccer, basketball). For activities such as walking, running, and cycling, speed (ie, average time per mile) and distance were also queried to provide an approximate indicator of intensity.

Physical activity level: Reported leisure-time activities performed over the course of the day were assigned an energy expenditure value (METs) based on the *Compendium of Physical Activities* by Ainsworth *et al*.[15] Like the PAL, MET values are expressed as multiples of the RMR or the ratio of the metabolic cost of a given activity divided by the RMR. For example, a MET value of 1 is roughly equal to the RMR ($\sim$1 kcal (kg hr)$^{-1}$ for a 70 kg person); a MET value of 3 would indicate a metabolic cost three times that of the RMR. To estimate the daily PAL, MET values for all reported leisure-time activities, as well as other active and passive activities, were multiplied by the time per day spent in the given activity and then summed over all daily activities.

In order to estimate the PAL over 24 h in the ACLS cohort, a number of assumptions were made about behaviors that were not measured directly. Time spent sleeping was assumed to be 8 h at a value of 0.9 METs h^{-1}. Study participants were employed almost exclusively in professional or executive positions, and thus, were sedentary at work. We therefore assumed that the cohort spent about 12 h day^{-1} sitting (2 h of passive sitting at 1.0 METs h^{-1}; 7 h of sitting during occupational tasks at 1.5 METs h^{-1}; and 3 h of sitting for eating/self-care/miscellaneous home activities at 1.7 METs h^{-1}). Time spent in incidental activity was calculated as residual time after all other activity time was accounted for in the day (eg, 24 h −8 h (sleeping) −12 h (sitting)−reported LTPA time = incidental time). We assumed that incidental time was predominantly spent in personal care activities and in light household activities and such activity was assigned a MET value of 2.0.

The daily PAL score was expressed as average METs over a 24-h period (METs 24 h^{-1}). Change in PAL score was calculated as the difference in PAL between the first and the third examinations. These two time points were chosen to maintain some prospective timing of the exposure information relative to the study outcome and to ensure adequate time between examinations for change to occur. PAL was then categorized into three ordinal groups based on cutpoints previously established from laboratory studies of energy expenditure using doubly labeled water,[13] with further adjustments made based on the distribution of this variable in our study population. A baseline PAL $<$1.45 METs 24 h^{-1} was categorized as *low*; a PAL 1.45–1.60 METs 24 h^{-1}, categorized as *moderate*; and a PAL $>$1.60 METs 24 h^{-1}, as *high*. Change in PAL category between the first and third examinations was considered the exposure factor with regard to the risk of weight gain.

Analysis

Univariate statistics (mean (s.d.) and frequencies (percent)) were first calculated for the primary study variables, as well as for the selected demographic characteristics and potential confounding variables. Analysis of variance (ANOVA) and covariance (ANCOVA) compared simple and adjusted mean weight change between the first and fourth examinations (ie, the follow-up period) among categories of PAL at baseline and at the third examination (ie, the exposure period), and specific differences in body weight change among the categories were tested using linear contrasts.

A multivariable random coefficient regression model[16] then was used to determine the longitudinal relations of the *baseline* PAL and *changes* in the PAL between the first and third examinations with the *trajectory of body weight change* over the follow-up period. This modeling accounts for between-subject variation in baseline body weight (intercept) and the change in body weight per year of follow-up (slope) through the inclusion of random effects. For these analyses, repeated body weight assessments over four examinations were modeled as the outcome variable, while adjusting for baseline age, height, and smoking status. As change in smoking habit is a confounder of the relation between change in PAL and weight change, we also included the change in smoking status between $exam_1$ and $exam_3$ in the model. For this modeling, *change* in the PAL was first considered as a continuous variable (eg, PAL score) and then, for descriptive purposes, as a categorical variable (eg, PAL category). Two-way interactions of follow-up time with baseline PAL and changes in the PAL were included in all modeling to represent the dependence of the PAL-weight change relation on this variable. In addition, all other moderately significant ($P<0.20$) two-way interactions between the study variables (including baseline body weight) and follow-up time were included, as well as the significant three-way interaction between baseline PAL, change in PAL score, and follow-up time. Multicolinearity among the covariables was determined by inspection of the parameter estimates after the separate removal of each independent variable from the full model.

Results

The average length of follow-up from the first to the fourth examination was 5 y (range = 2–26 y), with 50% of the cohort being followed between 3 and 6 y. The average time between each of the examinations was similar ($\sim$1.7 y). The cohort was primarily white (97%) and nonsmoking (86%), with an average age of 41$\pm$7 y at baseline. Reported daily physical activity was relatively low; indeed, among the entire cohort, the average daily PAL was 1.46$\pm$0.09 METs 24 h^{-1}, with 57% of the cohort reporting the lowest possible PAL score (1.41 METs 24 h^{-1}). Subject characteristics by PAL at baseline are presented in Table 1. There were no differences among the PAL categories in age or follow-up time. Baseline body weight was lower for those with a *high*, compared with a *moderate* or *low* PAL at baseline, although, surprisingly, those with a *moderate* or *high* PAL gained more weight over the follow-up compared with their less active counterparts ($P<0.01$).

Figure 2 displays the adjusted difference in body weight between baseline and the fourth examination according to the PAL category at baseline and at the third examination based on ANCOVA. Among persons initially in the *low* PAL category, those who increased their daily PAL to the *moderate* or *high* category by the third examination actually lost weight over the 5-y follow-up period ($P<0.001$). Being of *moderate* PAL at baseline and then maintaining that PAL or decreasing to the *low* category by the third examination resulted in a 5-y weight gain of nearly 1 kg, whereas increasing from a *moderate* PAL to a *high* resulted in attenuated weight gain (0.3 kg). Among persons with the highest PAL at baseline, at least maintaining that *high* PAL resulted in a significantly minimized weight gain over 5 y compared with the more active persons who decreased their activity over time, although these estimates were not statistically significant.

The *predicted trajectory of weight change* over time per change in the continuous PAL score between the first and third examinations, based on the multivariable random coefficient regression modeling is shown in Figure 3. The regression coefficient for the quadratic term for follow-up time in this analysis (time*time beta = 0.03; 95% confidence intervals (CI): 0.02, 0.03) indicates a curvilinear slope for weight gain (ie, *accelerated* weight gain) over the follow-up

Table 1 Baseline characteristics of the 4-examination cohort: ACLS, 1970–1998

	Baseline PAL category		
	Low (n = *1672*)	*Moderate* (n = *641*)	*High* (n = *188*)
Average PAL	1.42 ± 0.01	1.51 ± 0.04[1,3]	1.72 ± 0.12[1,2]
Weight (kg)	81.4 ± 10.5[3]	81.0 ± 10.4[3]	77.3 ± 7.8[1,2]
Age (y)	40.9 ± 7.2	41.2 ± 7.1	41.2 ± 6.8
% Smokers	18	111	7[1]
Follow-up (y)	5.1 ± 3.3	5.0 ± 2.8	5.3 ± 2.7
Weight change ($exam_1$ to $exam_4$)	0.1 ± 4.9	0.8 ± 4.8[1]	1.1 ± 3.9[1]

Data are mean ± s.d. or %; [1,2,3]Significantly different ($P<0.01$) from column 1, 2, or 3 based on ANOVA or χ^2 tests.

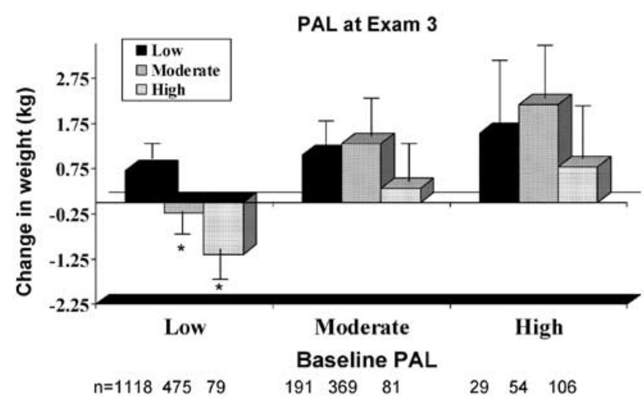

Figure 2 Adjusted mean difference in body weight between baseline and $exam_4$ by change in PAL category between $exam_1$ and $exam_3$. The PAL categories are: *low* (<1.46 METs 24 h^{-1}); *moderate* (1.46–1.60 METs 24 h^{-1}); and *high* (>1.60 METs 24 h^{-1}). *Significantly different from *low-low* category ($P<0.001$) after adjusting for baseline age and follow-up time using ANCOVA.

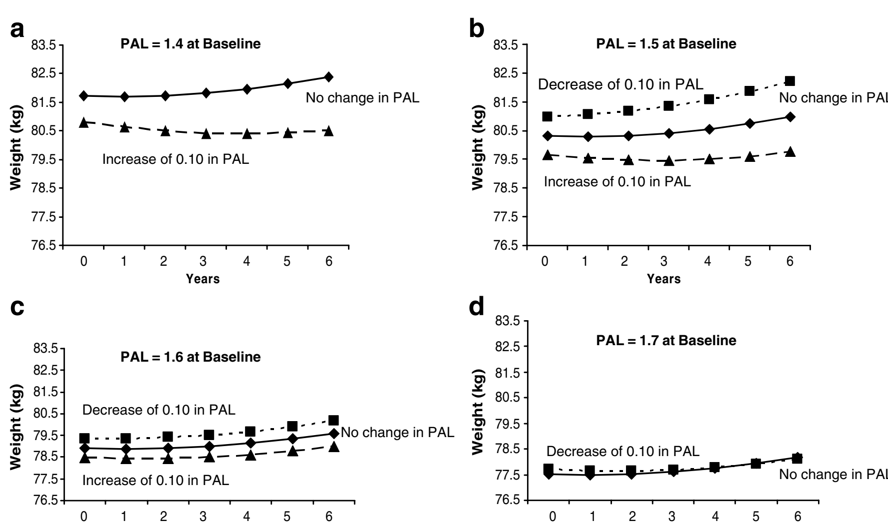

Figure 3 (a–d) Predicted weight change over time by change in PAL score between $exam_1$ and $exam_3$, based on PAL score at baseline. Estimates are adjusted for baseline age, height, smoking, follow-up time, change in smoking between $exam_1$ and $exam_3$ and the interaction of each of these variables (including baseline weight) with follow-up time using multivariable random coefficient regression modeling.

period among those maintaining the same PAL score between the first and third examinations (reference group). Although baseline PAL score significantly altered the trajectory of weight change (PAL*time beta = 0.05; 95%CI: 0.01, 0.09), the *change* in PAL score from $exam_1$ to $exam_3$ affected body weight change in a more significant way (PAL change*time beta = −0.12; 95%CI: −0.16, −0.07). On average, a change (increase or decrease) of 0.10 METs 24 h^{-1} in the PAL between the first and third examinations resulted in a weight change (loss or gain) of 0.12 kg^{-1} compared with the referent group whose PAL remained stable at 1.46 METs 24 h^{-1}. These findings were not affected by baseline age, height, or smoking; however, the magnitude of the estimates varied significantly by baseline PAL score (PAL*PAL change*time beta = 0.02; 95%CI: 0.00, 0.04). Those persons with the lowest PAL at baseline experienced the greatest benefits from increasing their activity level compared with their counterparts who were more active at baseline. For instance, men with an initially low PAL of 1.40 who then improved their PAL by 0.10 METs 24 h^{-1} between $exam_1$ and $exam_3$, actually lost weight over the follow-up (0.30 kg; Figure 3a). On the other hand, men with a higher baseline PAL of 1.60 who increased their PAL score by 0.10 METs 24 h^{-1} during this same time period *gained* weight (0.53 kg), although this weight gain was minimized relative to their active counterparts whose activity level decreased or remained stable (Figure 3c).

Regression estimates for weight change over time by *categorical* change in PAL are presented in Figure 4 for the PAL change categories that differed significantly from the reference group (*low/low*). Categories that did not differ significantly, such as the *high/high* group, are not shown. Those persons in the *low* (<1.45 METs 24 h^{-1}) PAL category at baseline and at the third examination *(low/low* — referent group) experienced a curvilinear change in body weight with a weight gain occurring after the first 2 y of follow-up (time*time beta = 0.03; 95%CI: 0.02, 0.03). *Again, this curvilinear weight gain was markedly accelerated among some subjects*. For instance, those who maintained a *moderate* (1.45–1.60 METs 24 h^{-1}) PAL between the two examinations gained 0.15 kg^{-1} more ($P<0.05$) and those who decreased their PAL from *high* to *moderate* gained 0.30 kg^{-1} more ($P<0.05$) than those who maintained a *low* PAL. Weight gain among persons maintaining a *high* (>1.60 METs 24 h^{-1}) PAL was not significantly different than among those maintaining a *low* PAL. Conversely, persons who increased their activity from *low* to *moderate* or from *low* to *high* actually lost weight over the follow-up compared with those who remained in the *low* category (0.18 and 0.31 kg^{-1}, respectively; $P<0.001$). These findings were not affected by baseline age, height, smoking, change in smoking or the interaction of each of these with follow-up time.

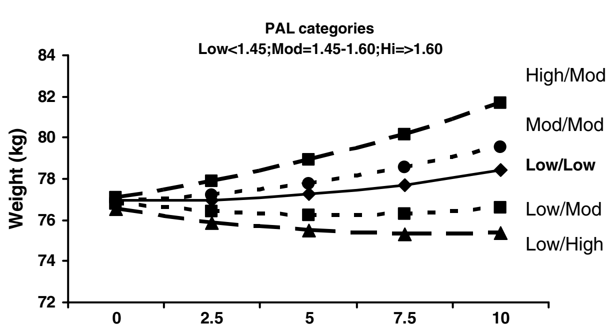

Figure 4 Predicted weight change by categorical change in the PAL between $exam_1$ and $exam_3$. The solid line is the referent group (Low/Low) and all other lines are significantly different ($P<0.05$) from the referent group. Estimates are adjusted for baseline age, height, smoking, follow-up time, change in smoking between $exam_1$ and $exam_3$ and the interaction of each of these variables (including baseline weight) with follow-up time using multivariable random coefficient regression modeling.

Discussion

There was a small curvilinear weight gain over the follow-up among people who maintained *low* and *high* levels of activity between the first and third examinations, although weight gain was minimized among those maintaining a *high* (>1.60 METs 24 h^{-1}) PAL relative to those who consistently reported a *moderate* (1.45–1.60 METs 24 h^{-1}) PAL. Weight gain was *accelerated* further among those who *decreased* their activity (PAL) level from *high* to *moderate*. A shift from the *low* (<1.45 METs 24 h^{-1}) PAL category to the *moderate* or *high* category was necessary for weight loss over time. These estimates were not altered by a number of factors known to influence both physical activity and body weight in middle-age — namely, age, height, or smoking; however, the magnitude of the estimates varied significantly by baseline PAL level. Those persons with the lowest initial PAL experienced the greatest benefits from increasing activity compared with men who were more active at baseline. This is important as it could motivate even the most sedentary persons to make small improvements in their daily energy expenditure. Improvements of 0.10 METs 24 h^{-1} for a person with a low PAL of 1.4 METs 24 h^{-1} could easily be achieved by adding daily stair climbing (rather than elevator use) and by walking short distances (<1 mile) to perform errands commonly performed by automobile.

These data are consistent with our previous findings from ACLS participants[8] among whom we observed attenuated age-related weight gain with higher levels of cardiorespiratory fitness. Moreover, *improvements* in fitness level were necessary for weight loss over the 7.5 y follow-up; simply maintaining the same level of fitness (even among the most fit subjects) was not sufficient. In the current report, we attempted to estimate the PAL using general assumptions about lifestyle activity patterns of the well-educated professionals comprising our study cohort and we used four assessments of body weight over the follow-up period, rather than only two. Interestingly, those persons initially having a *high* average daily PAL at baseline continued to experience small amounts of weight gain despite increases in the PAL between the first and third examinations (Figure 3d); these same men who later decreased their activity level to *moderate* were the most vulnerable with regard to accelerated weight gain (Figure 4). These particular men may be genetically predisposed toward heavier body weight and perhaps relied on sport or other vigorous activity to control it in their younger adulthood. Together with our previous findings and others,[9,10] these data suggest that increasing levels of physical activity may be necessary to effectively maintain a constant body weight with increasing age. Moreover, among men who may have a genetic predisposition toward obesity, even greater increases in activity may be necessary to maintain weight compared to men who are less vulnerable to weight gain.

How much daily physical activity is enough?

The amount of daily energy expenditure required to maintain a healthy body weight is controversial and, most likely is dependent upon age, sex, race, energy intake, and the outcome objectives (eg, prevention of overweight *vs* weight loss or the prevention of weight regain after weight loss in obese populations). The current physical activity guidelines for adults of 30 min or more of moderate level activity on most days of the week[17] is sufficient for reducing the risks for a number of chronic diseases. For preventing weight gain or weight regain following obesity, however, this recommendation is most likely insufficient for some, perhaps many, in the general population given the current social environment. The current consensus statement from the International Association for the Study of Obesity[18] recommends 60–90 min day^{-1} of moderate intensity exercise or about 35 min day^{-1} of vigorous activity for the prevention of weight *regain following obesity*. Although epidemiologic and laboratory data are limited, it appears that about 45–60 min day^{-1} of moderate activity is necessary to prevent *the transition from normal weight to obesity*, at least for a large part of the population.

Hill *et al*[5] propose meaningful weight gain as $\sim$0.82–0.91 kg y^{-1} based on population weight gain estimates from the CARDIA[9] and NHANES[1] studies. Our current data from the ACLS cohort suggest that an average daily PAL $>$1.60 METs 24 h^{-1} is necessary to prevent meaningful weight gain through middle age. In order to accomplish an average level of daily activity that is 60–70% above the RMR, Westerterp[11] recommends exchanging passive or very low intensity activities (ie, those involving sitting) for moderate intensity activities that have energy requirements of about 4–6 METs. He further proposes that moderate intensity activities have a substantially greater impact on the PAL than vigorous activities, since vigorous activity is usually performed for very short periods of time and then is compensated for by reduced volitional activity throughout the remainder of the day. This suggests that the best way to increase the average daily PAL from 1.4 (sedentary) to 1.6 (active) is to add about 45–60 min of activity performed at 4–6 METs (brisk walking or cycling) to the daily routine.

This study has several strengths in that it comprises a relatively large cohort and utilizes multiple assessments of measured body weight over several years. Moreover, this is the first study to use the PAL as an indicator of reported daily energy expenditure in a large cohort study. There are, however, some limitations to the analysis that should be addressed. First, house- and yard-work activities were not assessed directly in this study, but were counted as incidental activity (2 METs). This may have under-represented the daily PAL if these activities were performed at a MET value $>$2 METs. Indeed, if these particular activities are performed often, this under-representation of house- or yard-work may partially explain an average daily PAL among the cohort that is relatively low (1.46 METs 24 h^{-1}). On the other hand, our assumptions regarding the lifestyle activity habits of this affluent, professional male ACLS cohort may be accurate. In any case, if the average daily PAL were under-represented, we assume that it would remain such when it was assessed again at follow-up examinations thereby adding no bias to the findings. However, care should be taken in generalizing these findings to the general population of middle-aged persons among whom house- or yard-work activity may be greater than that of the ACLS cohort and who may have greater occupational energy expenditure. Finally, the PAL was originally derived based on direct measurements of metabolism using doubly labeled water, and thus, it is not a measure of body movement, *per se,* but rather, of simple energy expenditure. We estimated the average daily PAL based on reported physical activities and other daily routines, and the metabolic costs assigned to these reported activities do not account for variations in RMR or fat free mass among the study population. Therefore, it is inappropriate to compare our findings to those derived from doubly labeled water assessments on small study samples in a laboratory setting.

Primary prevention of substantial weight gain with age is probably more efficacious than weight loss efforts in reducing the risk of obesity and obesity-related morbidity and mortality in the United States. We observed an inverse relation between daily PAL and weight gain in a cohort of men, aged 25–55 y. As hypothesized, increasing to or maintaining a daily physical activity level at least 60% above the RMR (ie, PAL $>$1.60 METs 24 h^{-1}) may be necessary (at least for many individuals) to maintain body weight through middle-age and can be achieved easily by incorporating 45–60 min of brisk walking, gardening/yardwork or cycling into the daily routine.

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