Does physical activity prevent weight gain – a systematic review

M. Fogelholm[1] and K. Kukkonen-Harjula[2]

[1] University of Helsinki, Palmenia Centre for Research and Continuing Education, Lahti, Finland; [2] UKK Institute for Health Promotion Research, Tampere, Finland.

Received 7 June 2000; revised 13 July 2000; accepted 14 July 2000

Address reprint requests to: Dr Mikael Fogelholm, University of Helsinki, Palmenia Centre for Research and Continuing Education, Saimaankatu 11, Fin-15140 Lahti, Finland.
E-mail: mikael.fogelholm@helsinki.fi

Summary

This paper is a systematic review of research data on associations between physical activity and weight gain, with or without prior weight reduction. The selected studies were restricted to Caucasian (white) adults. Most studies with data on physical activity collected at follow-up, found an inverse association between physical activity and long-term weight gain. This finding was present in studies both with and without prior weight reduction. Prospective studies with physical activity measured at baseline, and randomized weight reduction interventions, gave inconsistent results regarding the effects of increased physical activity on weight change. The weighted mean weight regain in randomized studies with or without exercise training was 0.28 and 0.33 kg/month, respectively. Based on observational studies, it seemed that an actual increase in energy expenditure of physical activity of approximately 6300–8400 kJ/week (1500–2000 kcal/week) is associated with improved weight maintenance. This is more than was prescribed in most randomized trials, and certainly more than the participants actually achieved. Adherence to a prescribed exercise programme remains a big challenge. Before new methods to improve exercise adherence are found, the role of prescribed physical activity in prevention of weight gain remains modest.

Keywords: Exercise, obesity, physical activity, weight maintenance.

obesity reviews (2000) **1**, 95–111

Introduction

The prevalence of obesity has increased in all parts of the world during past decades (1). There are two main, complementary strategies in tackling the increasing problem of obesity (2). The first strategy is to prevent individuals from becoming obese, i.e. to prevent weight gain. The second is to improve the efficacy of weight reduction. Because of several methods to improve weight loss, initial weight loss success is no longer a major problem (3). However, maintenance of the reduced body weight is much more difficult and a substantial proportion of patients will eventually return towards their initial body weight (2–4). Therefore, prevention of weight gain (with or without prior weight loss) is the general strategy to tackle the obesity epidemic.

Because both weight gain and loss are functions of energy balance, prevention of weight gain could theoretically be achieved by changes in both dietary energy intake and physical activity (energy expenditure). Weight reduction by increased physical activity without restricted energy intake is only modest (5,6). In contrast, many recent reviews have underscored the important role of physical activity in prevention of weight gain (3,7–9). However, because of the narrative nature of most reviews available, there is clearly a need for a systematic scrutiny of studies on the associations between physical activity and weight change.

The purpose of this study was to review systematically all research reports, published between the 1980 and early 2000, with data on physical activity and weight gain or weight regain (after weight reduction). Both prospective, observational studies and randomized clinical trials were included in the review. The conclusions are restricted to Caucasian (white) adults.

Methods

We searched for research reports divided into four types of studies: (1) prospective, observational studies (no intervention); (2) studies with a non-randomized (as regards to exercise) weight reduction phase and a prospective, observational follow-up; (3) randomized weight reduction interventions with a passive follow-up; (4) non-randomized weight reduction interventions with a randomized weight maintenance phase and a passive follow-up (i.e. studies with an intention to improve weight maintenance by a specific intervention after the weight reduction). Both design and subjects affected the inclusion and exclusion of studies. To reduce the number of potentially confounding variables, we restricted our study to Caucasian (white) adults. In addition, no study population was allowed to be composed solely of patients with a chronic disease (e.g. hypertension, diabetes). The mean age of the populations at the time of entry to the study was restricted to between 18 and 50 years.

The inclusion criteria for the prospective, observational studies were as follows:

- Data on physical activity (any component, at any time-point) and change of weight (or body mass index, BMI);
- Duration of follow-up >2 years;
- No intervention;
- Studies on weight change during special circumstances, e.g. after smoking cessation or during or after pregnancy, were excluded.

The inclusion criteria for the non-randomized weight reduction interventions with a prospective, observational follow-up were as follows:

- Overweight (BMI >25) or obese (BMI >30) subjects before weight reduction;
- Weight reduction >5% of initial body weight;
- Data on physical activity and weight (or BMI) changes after weight reduction.
- No randomization to exercise training and control (no exercise) during or after weight reduction; however, randomization according to a treatment without an apparent effect on physical activity was accepted (e.g. use of aspartame vs. placebo);
- Duration of follow-up: >1 year after the end of weight reduction.

The inclusion criteria for randomized weight reduction interventions were as follows:

- Degree of overweight and magnitude of weight reduction as in the non-randomized interventions;
- Data on physical activity and weight (or BMI) changes after weight reduction;
- Randomization to exercise training vs. no exercise (with or without diet) before weight reduction;
- Duration of follow-up: >1 year after the end of weight reduction.

The inclusion criteria for non-randomized weight reduction interventions with a randomized weight maintenance phase were as follows:

- Degree of overweight and magnitude of weight reduction as in the non-randomized interventions;
- Data on physical activity and weight (or BMI) changes after weight reduction;
- Randomization to exercise training vs. no exercise (with or without diet) after weight reduction, before the weight maintenance phase;
- Duration of follow-up: >1 year after the end of weight reduction and >6 months after the end of the weight maintenance phase.

The rational for choosing 5% as the minimal magnitude of weight reduction in interventions was based on the fact that this level is regarded as the smallest loss with health-enhancing effects (1). The choice of the minimal duration of follow-up (>1 or 2 years, depending on the type of study) was arbitrary. Too long a period would have restricted the number of accepted studies too much, and too short a period would have told very little about weight maintenance. Our choice was a subjective compromise between these two factors.

We searched the MEDLINE (1980 – early 2000) database by using the following search strategy: ((((weight[text word] AND (((gain[text word] OR change[text word]) OR maintenance[text word] OR management[text word] AND (((exercise[text word] OR physical activity[text word] OR walking[text word] OR training[text word])) AND human[MeSH terms] AND English[language] AND (((trial[all fields] OR follow*[all fields] OR observation*[all fields] OR prospective[all fields])). This search yielded 1012 titles. All potentially relevant abstracts were read, and out of those, all potentially relevant full reports were retrieved. Moreover, we used the reference lists of some recent, comprehensive reviews and consensus meetings (6–10).

The studies identified associations between exercise and weight gain, and effects of exercise on prevention of weight regain, in different ways. We present data of all the included studies in Tables 1–4. The results of the randomized studies were also analysed quantitatively by calculating the weighed (by number of subjects) mean weight regain (from the end of the weight reduction to the end of follow-up) separately for groups with and without

Table 1 Physical activity and weight gain: a summary of prospective, observational studies

First author (reference)	Subjects (sex, age at entry)	Follow-up (years)	Assessment of physical activity	Statistical adjustments	Main effects of PA	Description of the results
Rissanen (11)	6165 M, 6504 W (25–64 y)	5.7 y (median)	Leisure PA at follow-up (questionnaire, 3 categories: frequent, occasional, rare)	Age, BMI, education, marital status, parity, smoking, alcohol, coffee, health status	+	PA at follow-up was inversely associated with wt gain in men and women
Klesges (12)	142 M, 152 W (mean 34 y)	2 y	Leisure sports activity and occupational PA score (Baecke PA scale) (data collected annually)	Baseline wt, diet, pregnancy, smoking, alcohol, family risk of obesity	+/ns/–	Baseline work ($\beta = -3.5$) and leisure ($\beta = -6.2$) activity predicted wt loss in W, but not in M. Baseline sports activity predicted wt gain in W ($\beta = 3.0$) and M ($\beta = 1.9$)
Owens (13)	500 W (42–50 y)	3 y	Leisure habitual PA (Paffenbarger questionnaire; kcal/wk)	Sex-hormone use, smoking change in menopausal status	+	Both baseline PA and increased PA were associated with less wt gain
Williamson (14)	3515 M, 5810 W (mean 47 y)	10 y	Nonrecreational and recreational PA (3-point scale)	Age, BMI, race, education, smoking status, alcohol, physician-diagnosed health conditions, parity	+	Wt change was inversely associated with PA at follow-up. Decreased PA was associated with wt gain. Baseline PA was not associated with wt change
Taylor (15)	568 M, 668 W (20–60 y)	7 y	Moderate and heavy PA. TV watching (h/day)	Age, smoking, sex	+	Increased PA (compared to stable or decreased PA) was associated with less wt gain
Bild (16)	1100 M, 1096 W (18–36 y)	2 y	PA score (intensity and duration of PA at leisure and work)	Age, BMI, perception of fatness, physical fitness, education, smoking, diet, alcohol	ns/–	Low baseline PA predicted wt loss (OR = 0.05) in M. Change in PA was not associated with wt change
Haapanen (17)	2564 M, 2695 W (19–63 y)	10 y	Leisure PA (scores, grouped into tertiles) and single-item self-assessment of total PA (4 classes)	Age, perceived health status, smoking status and socioeconomic status	+/ns	No regular PA at baseline was associated with >5 kg wt gain in W (OR = 1.63), but not in M (vigorous activity twice wk was used as reference). Inactivity at follow-up was inversely associated with wt gain in both genders (OR = 2.59 – 2.67). Becoming physically inactive was also associated with wt gain (OR = 1.96 – 2.49)
Heitmann (18)	2110 M, 2490 W (twin pairs) (18–39 y)	6 y	PA during leisure (classified into 3 classes by tertiles of total MET values) at follow-up	Age, smoking, zygosity, BMI at entry, change in BMI of the twin pair	ns	PA at follow-up was not associated with wt change (multiple regression)
Kahn (19)	35156 M, 44080 W (mean 40 y)	10 y	Jogging, aerobics, tennis, gardening and walking (h/wk). Both baseline and follow-up data were queried at follow-up	Age, education, region of the country, BMI at entry, BMI at age 18 y, marital status, diet, alcohol, smoking, menopausal status, oestrogen use, parity	+	Compared with no activity, jogging >1 h/wk (M,W), aerobics >1 h/wk (M) or >4 h/wk (W), tennis 1–3 h/wk (W), gardening >1 h/wk (W) or >4 h/wk (M) and walking >4 h/wk were associated with significant BMI loss (mean –0.08 to –0.49 kg m^{-2})
Parker (20)	176 M, 289 W (mean 47 y)	4 y	Participation in aerobic activity (dichotomous) at baseline		ns	No association between baseline aerobic EX and subsequent weight change (tertiles)
Barefoot (21)	3885 M, 841 W (mean 19 y)	21 y	h/wk (questionnaire) at follow-up	BMI at entry, smoking, gender, depression	+	EX was negatively correlated with wt gain ($\beta = -0.88$)

Table 1 *Continued*

First author (reference)	Subjects (sex, age at entry)	Follow-up (years)	Assessment of physical activity	Statistical adjustments	Main effects of PA	Description of the results
Coakley (22)	10 272 M (44–54 y)	4 y	Vigorous PA (min/wk), TV/VCR watching (h/wk) (questionnaire)	Age, diet, smoking, baseline values (including PA and TV/VCR use)	+	Vigorous PA (β = –0.16) and TV/VCR use (β = 0.02) at follow-up (adjusted to baseline values) were associated with wt change
French (23)	228 M, 892 W (mean 35 y)	4 y	Leisure PA score (annual questionnaire)	Age, diet, baseline values	ns	The cumulative duration of increased PA was not significantly associated (β = –0.035) with wt loss
Guo (24)	102 M, 108 W (mean 44 y)	9.1 y (mean)	Leisure and occupational PA score; individuals divided into 3 PA groups (biannual questionnaires)	Age, menopausal status, duration of oestrogen use	+/ns	Compared with high PA (throughout the entire study period), low and medium PA were associated with wt increase (2.8 and 1.8 kg, respectively) in M, but not in W
Crawford (25)	176 M, 705 W (20–45 y)	3 y	TV watching (h/day)	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 were not associated with wt change
Fogelholm (26)	442 M (36–49 y)	10 y	Leisure PA score (intensity × duration × frequency)	Age, weight at age 20, weight at entry, chronic diseases, smoking, occupational class, diet, alcohol, marital status, former sports training	+/ns	Increased PA was negatively associated (β = –2.23) with wt change. No association for decreased PA, continuous high PA or continuous low PA vs. wt change

Abbreviations: β = beta coefficient in multiple regression, BMI = body mass index, EX = exercise, h = hour(s), M = men, MET = metabolic equivalents, ns = no significant association between physical activity and weight maintenance, OR = odds ratio, PA = physical activity, W = women, wk = week(s), wt = weight, *y* = year(s), + = physical activity associated with better weight maintenance; – = physical activity associated with poorer weight maintenance.

prescribed exercise training. Because of divergent study designs, analytical methods and presentation of the results, the longitudinal, observational studies were not treated quantitatively.0-

Results

Prospective, observational studies

Sixteen studies (11–26) were accepted as prospective, observational studies (Table 1). Four studies (11,14, 19,22) had more than 10 000 participants, and six (12,13,20,24–26) less than 1000. The mean duration of the follow-up was approximately 7 years, with a range from 2 to 21 years.

All studies used a retrospective questionnaire to assess the habitual (usually for the past year) level of physical activity. Three studies (11,20–24) used a rough, subjective classification into two or three activity classes. Most studies assessed physical activity of both moderate intensity, and more intense activities. Two studies were interested in more vigorous exercise activities (15,22). Three studies also assessed occupational (or nonrecreational) activity (12,14,24). Finally, Coakley and co-workers (22) and Crawford and co-workers (25) asked specifically about television and video (TV/VCR) use.

In statistical analyses most studies made adjustment for age, smoking, and baseline BMI. Six studies used adjustments for the habitual diet (12,16,19,23,25,26). Health status (perceived or physician-diagnosed) was used as an adjusting factor in four studies (11,14,17,26).

We grouped the outcomes of the studies according to when physical activity data were collected, i.e. whether baseline, follow-up or change (from baseline to follow-up) in physical activity was compared against change in weight. Results from the studies using baseline physical activity data were inconsistent. Three studies (12,13,17) reported an inverse relationship between baseline physical activity and weight change, i.e. a large volume of physical activity predicted smaller weight change. However, Haapanen and co-workers (17) reported an inverse relationship only for men, not for women. High baseline work activity was

Table 2 A summary of observational studies with weight regain after intentional weight reduction. All subjects were initially overweight or obese

First author (reference)	Subjects (gender, mean age, weight and BMI)	Weight reduction and maintenance (duration, method, amount)	Follow-up (time after intervention, measurements, n)	Assessment of physical activity	Statistical adjustments	Main effects of PA	Description of results at follow-up
Hoiberg (27)	268 M, 923 W, age 35 y, wt 107 kg (M), 86 kg (W)	18 mo WR by a ketogenic (1000 kcal, 80 E% as fat) diet. Mean wt loss 12.7 kg (M) and 9.6 kg (W)	1 y, 155 M, 531 W assessed (58%)	Questionnaire on strenuous PA	Eating behaviour, feelings while dieting (multiple regression)	+	PA was related to success (achieved WR goal without gaining wt during the follow-up)
Jeffery (28)	89 M, age 53 y, BMI 32	BT in groups (including EX) for 15 wk. Mean wt loss 13.5 kg. Re-contact at 3 months and 1 y	2 y, 81(91%) measured	Questionnaires at entry, 15 wk, 3 mo, 1 y. PA behaviour: duration and frequency of 13 types of PA during the prior week	Eating habits, attendance, psychological variables (stepwise regression)	+/ns	Post-treatment EX (total minutes), but not EX at 1 y follow-up, predicted (total minutes) wt maintenance at 2 y
Kayman (29)	108 W, age 41–47 y, wt or degree of overwt not given	Based on a retrospective questionnaire, subjects were classified in 3 groups: maintainers (*n* = 30); relapsers (*n* = 44); stable-weight controls (*n* = 34)	≥2 y. Cross-sectional interview based on a questionnaire (retrospective design)	Questionnaire on habitual 'EX patterns' (regularity); regular exercise means at least 3 x/wk for >30 min at time		+	90% of maintainers and 82% control subjects exercised regularly, vs. 34% of relapsers
Holden (30)	199 M + W, age 47 y, BMI 41 in those who were measured at follow-up	VLED + BT (including EX), mean duration 52 wk (range 8–260). Mean wt loss 31 kg	3.3 y (range 141–243 wk) 38 M, 80 W measured (59%)	Questionnaire on telephone: current EX duration (h/wk)	Baseline wt, overall wt loss, age, diet	+	Wt regain 18 kg(61%). Relative wt regain was 50% in exercisers and 76% in nonexercisers. EX time correlated negatively with wt regain
Hartman (31)	138 M + W, age 43 y, BMI 37 in those who were measured at follow-up	VLED + BT (mean 23 week), mean wt loss 25% (W) and 29% (M) of initial wt. 55% of subjects attended an optional maintenance programme (varying duration). Mean wt loss 27.2 kg	2–3 y. 29 M, 73 W assessed (74%)	Interview: PA during preceding 3 mo. Results as kcal/wk, subjects divided into 3 groups	Initial wt loss, participation in maintenance programme	+	W maintained 39% and M 45% of initial wt loss. The highest-level EX group maintained a larger wt loss (18 kg) than low-EX (9 kg) or no EX (6 kg) groups
Lavery (32)	123 M, 386 W age 45, wt 84 kg	BT (8 weekly sessions), mean wt loss 4.2 kg. Study design: retrospective (contact only at follow-up)	2 y	Change in PA since enrolment	Initial wt loss, several behavioural variables associated with the programme, eating habits	+	Subjects with increased PA (52%) had a larger wt loss (–4.2 kg) than those with no change in PA (–1.0 kg). PA did not enter the stepwise regression equation

Table 2 *Continued*

First author (reference)	Subjects (gender, mean age, weight and BMI)	Weight reduction and maintenance (duration, method, amount)	Follow-up (time after intervention, measurements, n)	Assessment of physical activity	Statistical adjustments	Main effects of PA	Description of results at follow-up
Harris (33)	202 M + W, age 38 y, BMI 31 in those who were measured at follow-up	WR: BT group meetings weekly for 20 wk. Mean wt loss not given. WM: diet 1000–1500 kcal/d + EX 1000 kcal/wk. Randomized into 5 groups (control, standard behavioural therapy, food/monetary incentives)	Final assessment 18 mo from beginning. 82 M 75 W assessed (78%).	PA logs for 20 wk, then 1 wk/month. PA questionnaire for the last 6 mo, results in kcal/wk	Gender, treatment group, treatment centre, diet. Multivariate ANCOVA with time-dependent covartiates	+	PA increased from 1000 to 1500 min/wk. Change in weekly EX was inversely related to change in BMI. EX accounted for about 4% in variance in BMI change
Haus (34)	62 M + W, age 49 y	WR behaviour orientated, 6 months, at worksite. Mean wt decrease 6 kg	6–42 months (mostly >24 months). 14 M, 15 W assessed (47%)	Questionnaire (PA during the previous month), activity as min/wk		+	PA was inversely related ($r = -0.34$) to the change in percent relative wt
DePue (35)	178 M + W, age 43	WR: Optifast treatment 26 wk, including VLED 12 wk and EX. WM: biweekly sessions 6 months and exercise (44% attended).Total mean wt loss 27 kg	10–38 months after WR (typically >2 y), 26 M, 75 W returned the questionnaire (57%). Based on their wt regain the subjects were classified as maintainers ($n = 31$) and regainers ($n = 76$)	Questionnaire returned anonymously: vigorous EX during the past month, number of weekly sessions, lasting >20 min		+	65% of the maintainers vs. 29% of the regainers reported EX >3 times per week
Ewbank (36)	55 M + W, age 50, mean BMI 35 in those who were measured at follow-up	VLED + BT + EX (23 wk), followed by diet + BT (16 wk) and a 10 wk WM. Mean weight loss during WR 28 kg	2 y after VLED. 17 M and 28 W were assessed (82%)	Paffenbarger's Harvard Alumni Physical Activity Survey → PA index (total EE , kcal/wk) at follow-up.	Baseline wt, age. Multiple regression analysis	+	Wt regain 15 kg (57%). PA was inversely related wt regain to (partial $r = -0.62$)

Walsh (37)	255 M + W, age 44 y, BMI 38	Optifast programme 26 wk (VLED 12 wk), including BT + EX. Mean attendance 18 wk Wt loss 27 kg (M) and 19 kg (W)	54 months after entry. 44 M, 99 F were assessed (56%). Questionnaire: self-reported wt (2.3 kg was added to wt given)	Questionnaire: weekly EX duration at follow-up		+	Regular exercisers exercised strenuously for 90 min/wk on average. Regular exercisers had a better wt maintenance than nonexercisers (9.6 vs. 1.3 kg of the 21 kg lost during WR)
Grodstein (38)	36 M, 156 W, BMI 38	Sandoz Nutrition programme: VLED or 1000 kcal diet for 12 wk, stabilization for 18–26 wk, WM for 26 wk (biweekly behavioural meetings), repeated if wished. Mean wt decrease 22 kg	Approximately 3 y from start. Mailed (or telephone) questionnaire. 192 assessed (out of 325)	Questionnaire: months of regular EX, EX h/wk, TV watching h/wk	Age. Multiple linear regression	+	EX frequency predicted wt maintenance: for every h/wk of EX there was a decrease in wt of 2 kg. Watching TV was associated with an increase in wt (0.3 kg for each h of TV)
Blackburn (39)	163 W, age 43 y, BMI 37	For WR (4 mo) and WM (12 mo): randomized into aspartame and no aspartame users. WR: 1000 kcal/d + BT + aerobic EX 200 min/wk. Mean wt loss 10 kg. WM: 1500 kcal/d + monthly group sessions + aerobic EX	3 y from end of weight reduction. 86 assessed (53%)	Daily EX (min/wk), logs min/wk for 1 wk before assessments	Aspartame use, eating control, hunger (linear regression model)	+	Wt change (from WR to follow-up) was inversely related to EX ($r = -0.32$)
Schoeller (40)	34 W, age 38 y, mean BMI 24 after WR	The subjects, who had lost ≥12 kg 1–3 mo before the start of the study, were prospectively followed for 1 y	1 y. 33 assessed (97%)	PA level (PAL = total EE/REE) measured by the doubly labelled water technique at entry		+	Physically most active subjects (PAL > 1.75) gained 2.5 kg vs. 9.9 kg in moderately active (PAL 1.55–1.75) and 7.0 kg in sedentary W (PAL <1.55)
Sarlio-Lähteen-korva (41)	51 W, age 58 y, wt	Successful Weight Watchers: maintained 40–90% of wt loss for >7 y ($n = 9$), compared to obese controls ($n = 42$). Cross-sectional, retrospective design	≥7 y from wt reduction	Open interview: lifestyle activity (habitual PA), weekly sports activities		+	More lifestyle activity in maintainers than in controls (89% vs. 39% of subjects). Similarly more weekly sports (67% vs. 13%)
Andersen (42)	40 W, age 43 y, BMI 31	16 week WR (structured aerobic EX or lifestyle activity; low-fat diet), mean wt loss 8.1 kg	1 y. 33 assessed (83%)	PA records (duration and intensity recorded) → daily activity units and estimated EE of PA during the entire follow-up		+	The most active third lost –2.0 kg vs. 0.3 and 4.9 kg gain in the middle and least active thirds

Table 2 *Continued*

First author (reference)	Subjects (gender, mean age, weight and BMI)	Weight reduction and maintenance (duration, method, amount)	Follow-up (time after intervention, measurements, n)	Assessment of physical activity	Statistical adjustments	Main effects of PA	Description of results at follow-up
McGuire (43)	102 M, 137 W, mean age 43–49 y	Telephone survey (population based sample): based on their wt-loss history, the subjects were divided into 3 groups: maintainers (*n* = 69, maintained >10% wt loss >1 y), regainers (*n* = 56, had regained wt loss of >10%), controls (*n* = 113, maintained current wt for the past 5 y)	>1 y (retrospective design)	Questionnaire: Leisure EX during the past wk, resulting in a total activity score. The number of weekly sweat-inducing EX. TV/VCR watching, h/wk	Gender, ethnicity, current BMI	+	Maintainers (vs, regainers and controls) had the highest number of strenuous activities (1.3/wk vs. 0.5 and 0.8), number of sweat episodes (2.8/wk vs. 1.8 and 1.9) and total activity score (27.8 vs. 16.2 and 18.2). No differences in time spent on TV/VCR, or in the number of mild or moderate intensity activities
McGuire (44)	343 M, 571 W, age 46	Members of National Weight Control Registry, inclusion criteria: wt loss of at least 13.6 kg with maintenance: for ≥1 y. Retrospective study subjects classified as maintainers (*n* = 420) and gainers (*n* = 248).	1 y after entry to the registry	Paffenbarger Activity Questionnaire: total and PA EE, in kJ/wk		ns	Total EE or types of PA at entry did not predict wt change. During the follow-up, total EE decreased less in maintainers (–437 kcal/wk) than in gainers (–818 kcal/wk)
Sarlio-Lähteen-korva (45)	606 M, 111 W	Individuals with BMI >27 from Finnish Twin Cohort who had lost ≥5% of wt and who maintained the loss for 9–15 y (maintainers; 38 M, 17 W) were compared to overweight persons (540 M, 68 W) and regainers(28 M, 26 W) from the same cohort	9 y (15 y follow-up of the cohort)	Questionnaire: current leisure PA, in MET h/d		ns	PA was not different between the groups

Abbreviations: BMI = body mass index, BT = behavioural therapy, d = day(s), E% = percent of energy, EE = energy expenditure, EX = exercise, M = men, MET = metabolic equivalents, mo = month(s), *n* = number of subjects, ns = no association between physical activity and weight-loss maintenance, PA = physical activity, PAL = physical activity level, r = correlation coefficient, REE = resting energy expenditure, VLED = very-low-energy diet, W = women, week = week(s), WM = weight maintenance intervention, WR = weight reduction, *y* = year(s), + = physical activity associated with better weight-loss maintenance.

Table 3 Physical activity and weight regain: A summary of randomized controlled trials with or without exercise during weight reduction. All subjects were overweight or obese initially

First author (reference)	Subjects	Weight reduction and trial design (*)	Exercise prescription	Follow-up	Results
Perri (46)	14 M, 76 W	20 wk. BT only, BT + EX. Mean wt loss 9.4 kg	4 × 20 min aerobic EX weekly	18 mo, including 6 mo maintenance support by mail and phone. 67 measured (74%)	Wt regain was similar in BT (3.1 kg) and BT + EX (3.3 kg) groups
Sikand (47)	30 W	4 mo. VLED only, VLED + EX. Mean wt loss 19.8 kg	Aerobic EX, 2 supervised weekly sessions (about 60–90 min/wk)	24 mo. 21 measured (70%)	Wt regain tended to be less in EX subjects (58% vs. 96%)
King (48)	155 M	12 mo. Diet only, EX only. Wt losses 7.2 kg (diet) vs. 5.0 kg (EX)	3 × 40–50 min brisk walking weekly + encouragement to increased lifestyle activity (120–150 min/wk)	12 mo. Randomized into support contacts by mail and phone vs. no contacts. 72 measured (70%); 48 in maintenance support	2 y wt regain was smallest (17%) in EX subjects with maintenance support. EX without support gained 71% and the diet groups 41–42% of wt loss
Pavlou (49)	160 M	8 wk. 4 different VLEDs (420–1000 kcal/d). Diet only, diet + EX (4 × 2 groups). Mean wt loss 13.3 kg	3 × 90 min EX weekly, including 35–60 min aerobic EX per session (270 min/wk)	18 mo. 110 measured (69%)	EX groups regained about 10% of the wt loss, whereas the diet groups regained 92%
Van Dale (50)	15 M, 39 W	Duration 12–14 wk. VLED only, VLED + EX. Mean wt loss 12.2 kg	Aerobic (2–3 h/wk) and fitness (2 h/wk) training (240–300 min/wk)	18–42 mo. 36 measured (67%)	In study 1, EX improved wt maintenance at 42 mo, but the difference was apparently caused by one outlier.
Skender (51)	66 M, 61 W	12 mo. Diet only, EX only, diet + EX. Mean wt losses 6.8, 2.9, 8.9 kg	Walking; target goal 5 × 45 min/wk (225 min/wk)	12 mo. 61 measured (48%)	Wt regain was similar in diet + EX vs. diet only groups. EX only lost and regained less
Wadden (52)	99 W	48 wk. Aerobic EX + diet, strength training + diet, aerobic EX + strength training + diet, diet only. Mean wt loss 15.6 kg	2–3 weekly sessions. Aerobic = step aerobics; strength = Universal Gym or Cybex equipment; combination = 40% aerobic, 60% strength (120–180 min/wk)	12 mo. 77 measured (78%)	EX did not affect maintenance of wt loss
Wing (53)	32 M, 122 W	6 mo. CON, diet only, EX only, diet + EX. Mean wt losses 1.5, 9.1, 2.1, 10.3 kg	Brisk walking, etc., 5 days/wk, target EE 6.3 MJ (1500 kcal) /wk	18 mo. 129 measured (84%)	EX did not affect maintenance of wt loss

Abbreviations: BT = behavioural therapy, CON = control subjects (no treatment), EE = energy expenditure, EX = exercise, M = men, mo = month(s), PA = physical activity, VLED = very-low-energy diet, W = women, week = weeks(s). (*) = weight loss by group is shown only in case of between-group differences.

associated with less weight gain in the study on Klesges and co-workers (12). In contrast, two studies reported that a large volume of vigorous physical activity at baseline was associated with greater weight gains (12,16). Finally, three studies did not find a significant association between baseline total physical activity (14,20), or TV/VCR watching (25), and the magnitude of weight change.

The results with physical activity data at follow-up were more consistent: Four studies found that a large volume of physical activity or exercise (11,14,17,21) at follow-up was associated with less weight gain. Only Heitmann *et al.* (18) did not find such an association.

Many studies used data on physical activity from both baseline and follow-up. Seven studies found that an

Table 4 Physical activity and weight regain: randomised controlled trials with or without exercise training after weight reduction

First author (reference)	Subjects	Weight reduction (method, amount)	Maintenance intervention	Follow-up	Results
Perri (54)	26 M, 97 W	BT. 12.4 kg in 20 wk.	6 months. Extended therapist contact (C) vs. C and social influence (S) vs. C and 4 × 20 min aerobic EX weekly vs. C, S and EX vs. no maintenance support	12 mo. 91 measured (74%)	All 4 conditions with maintenance support yielded better long-term wt losses than BT alone. EX did not significantly affect the results
Leermakers (55)	13 M, 54 W	Diet + BT. 8.8 kg in 6 mo.	6 mo. EX vs. wt-focused.EX = 150 min/wk, biweekly sessions, contingencies, relapse prevention training. 57 (85%) completed	6 mo. 48 completed (72%)	EX subjects gained more (4.4 kg) than the wt-focused subjects (0.8 kg) during months 6–12
Fogelholm (56)	85 W	VLED. 13.1 kg in 3 mo.	9 mo. Randomized into walking (2 groups, EX-1 = target EE 4.2 MJ/wk, EX-2 = 8.4 MJ/wk) and CON. All received diet instruction	24 mo. 74 measured (87%)	The mean wt regain after WR was 8.3 kg. Compared with the end of WR, wt regain at the end of follow-up was 3.5 (95% CI 0.2; 6.8) kg less in EX-1 vs. CON

Abbreviations: BT = behavioural therapy, CI = confidence intervals, CON = control subjects (no treatment), EE = energy expenditure, EX = exercise, M = men, mo = month(s), VLED = very-low-energy diet, W = women, WR = weight reduction intervention, wt = weight.

increase in physical activity was associated with less weight gain (13–15,17,22,24,26). Two studies did not find any associations between changes in physical activity (16), or in TV/VCR watching (25), vs. weight change. In the study of Fogelholm and co-workers (26), increased but not decreased physical activity was associated with weight change. French and co-workers (23) did not find an association between the cumulative duration of increased physical activity (annual recording) and weight change.

Non-randomized weight reduction studies with an observational follow-up

A total of 19 studies (27–45) were accepted as non-randomized weight reduction interventions with an observational follow-up (Table 2). In seven studies (29,38,40,41,43–45), the subjects were first contacted after the weight loss. The remaining 13 studies started with recruitment of participants for a weight reduction intervention. Hence, it was possible to calculate an attrition rate in these studies: compared to the start of weight reduction, an average of 70% (range: 47– 100%) of the subjects were assessed at the end of the follow-up. The duration of the follow-up was typically between 1 and 3 years. Only Sarlio-Lähteenkorva and co-workers (41,45) had >7 years follow-up.

Like the prospective, observational studies (Table 1), most of the studies cited in Table 2 used a retrospective questionnaire or an interview to assess physical activity. Three studies used a prospective activity record (33,39,42). Schoeller and co-workers (40) were the only people who measured total activity level by the doubly labelled water technique. Seven studies (27,29,30,35,37–39) focused on vigorous exercise, rather than lifestyle physical activity. Only half of the studies cited in Table 2 reported any statistical adjustments for confounding factors.

The results from the non-randomized interventions with a prospective follow-up were quite consistent: a total of 12 studies (27,29–31, 34–38,41–43) found that a large amount of physical activity at the follow-up measurement was associated with less weight regain after weight reduction. Only one study (45) did not report such an association. Four studies (32,33,39,44) used the change in physical activity from baseline (immediately after weight reduction) to the end of the follow-up: they all reported that increased physical activity was associated with a smaller weight regain. Using only baseline (after weight reduction) data on physical activity, however, brought less consistent results: Schoeller and co-workers (40) found that the amount of physical activity predicted weight maintenance, while McGuire and co-workers (44) did not find an association. Jeffery and co-workers (28) reported that physical activity immediately after weight reduction, but not 1 year later, predicted less weight regain at 2 years follow-up.

Randomized weight reduction interventions with a passive follow-up

Eight studies (46–53) were accepted as randomized interventions with a prospective follow-up of at least 1 years duration (Table 3). All these studies were evaluated on an intention-to-treat basis in the present review. The duration of weight reduction varied between 8 weeks and 12 months. Three studies used a very-low-energy diet (VLED) (47,49,50) during the weight reduction phase, while the other studies used a more conventional diet with restricted energy intake. Perri and co-workers (46) used only behaviour therapy in one group.

All studies used aerobic exercise (walking or ergometer cycling) with a target duration of approximately 1.5–3 h per week. In addition, Wadden and co-workers (52) had one group with strength training. The duration of follow-up was usually 1–2 years.

Only one study (49) found that exercise training during weight reduction lead to less weight gain during the follow-up, compared to non-exercising groups. Sikand and co-workers (47) reported a similar positive, but non-significant trend. King and co-workers (48) found that weight regain was smallest in exercising subjects randomized to supportive telephone contacts during the follow-up. However, those exercising subjects, who were randomized to no extended support, showed a tendency to regain even more weight than the diet-only subjects. van Dale and co-workers (50) reported better weight maintenance in one physical exercise group ($N = 5$), but the finding was apparently caused by an outlier (one of the exercising subjects had an exceptionally good weight maintenance). In contrast to the above results, four studies did not find exercise training to improve maintenance of reduced body weight (46,47,52–53).

Interventions with a randomized weight maintenance phase

Only three studies (54–56) were identified that fulfilled the criteria for non-randomized weight reduction interventions with a randomized weight maintenance phase after weight reduction (Table 4). According to the results, exercise training as a component of the maintenance intervention may have a positive, negative or an indifferent effect on weight maintenance.

Perri and co-workers (54) used several weight maintenance techniques, including aerobic exercise in two groups. All groups participating in the 6 month weight maintenance intervention had less weight gain, compared with the controls who were not contacted after the weight reduction. Nevertheless, the exercise groups did not succeed any better or worse than the other weight maintenance groups.

Finally, Leermakers and co-workers (55) randomized 67 subjects into exercise-focused and weight-focused groups after a 6 month weight reduction period. The exercising subjects met biweekly in supervised exercise session and they were also trained in relapse prevention strategies to avoid or cope with lapses in exercise. The weight-focused group learned problem-solving of weight-related difficulties, without emphasis on physical activity. During the unsupervised follow-up (6 months), the exercise-group gained more weight than the weight-focused group.

In the study of Fogelholm and co-workers (56), weight reduced, but still overweight or obese, women were randomized into control, moderate walking (target activity energy expenditure 4.2 MJ/week) and heavy walking (8.4 MJ/week). All groups received diet counselling. Compared with the end of weight reduction, weight regain at the 2 year follow-up was 3.5 (95% confidence interval 0.2–6.8) kg less in the moderate walking group vs. control subjects. The heavy walking group did not differ from the controls.

Quantitative analysis of the randomized studies

The quantitative results of all randomized trials are presented in Table 5. The mean duration of follow-up was 20 months. The difference between exercise and control groups' mean weigh regain in weight reduction trials was 1.8 kg (90 g/month), favouring a slightly better weight maintenance in the exercise groups. The respective difference in weight maintenance trials was 0.6 kg (50 g/month), with a trend for better maintenance in the control groups. The overall results suggested that prescribed exercise training may prevent weight regain by 50 g/month or about 600 g/year.

Discussion

Physical activity has been advocated as a key behavioural component in prevention of weight gain (3,7–9). Our systematic review shows, however, that the research results are highly dependent on study design, intervention adherence and analytic design. The most consistent finding was that a large volume of physical activity was associated with less weight gain – with or without prior weight reduction – if the level of activity was assessed in two conditions: only at the end of the follow-up period, or as a change from baseline to follow-up. In these studies, the nature of analysis is cross-sectional and retrospective (57). In contrast, the predictive value of physical activity, as measured before the follow-up (at baseline), remains uncertain. Similarly, the preventive effect of prescribed exercise training in randomized interventions was nothing more than modest.

The findings that a larger volume of physical activity, assessed at the end of follow-up, was associated with less weight gain may be interpreted in three different ways: First, physical activity may really prevent weight gain; second, less weight gain may lead to better exercise adherence; third, engagement in physical activity may be a proxy for a generally healthier lifestyle or psychological profile (e.g. better self-regulation). The fact that the more rigorous study designs (randomized trials) yielded very inconsistent results leads us to conjecture that the association between

Table 5 Quantitative summary of studies presented in Tables 4 and 5: Weighted mean weight change after weight reduction in randomised weight reduction or weight maintenance trials

First author (reference)	Follow-up (months)	Exercise groups			Control (non-exercise) groups		
		N	Weight change, kg	Weight change, kg/mo	N	Weight change, kg	Weight change, kg/mo
Weight reduction trials							
Perri (46)	18	18	3.3	0.18	17	3.1	0.17
	18	16	7.2	0.40	16	6.9	0.38
Sikand (47)	24	8	12.9	0.54	7	16.7	0.70
King (48)	12	21	0.8	0.07	20	3.2	0.27
	12	15	3.9	0.33	16	2.6	0.22
Pavlou (49)	18	10	2.2	0.12	11	3.1	0.17
	18	16	− 0.4	− 0.02	16	5.6	0.31
	18	15	3.1	0.17	13	8.6	0.48
	18	10	2.3	0.13	14	11.4	0.63
van Dale (50)	42	5	4	0.10	5	11	0.26
	36	5	14	0.39	6	5	0.14
	18	7	− 2	− 0.11	8	10	0.56
Skender (51)	12	21	4.4	0.37	15	6	0.50
Wadden (52)	12	21	5	0.42	21	8.4	0.70
	12	18	7.2	0.60			
	12	17	8	0.67			
Wing (53)	18	32	7.8	0.43	35	7.1	0.39
Weighted mean		(255)*	4.8	0.31	(220)	6.6	0.40
Weight maintenance trials							
Perri (54)	18	19	0.2	0.01	19	2.9	0.16
	18	18	3.9	0.22	19	1.8	0.10
Leermakers (55)	12	28	4.4	0.37	20	0.8	0.07
Fogelholm (56)	33	24	5.9	0.18	27	9.7	0.29
	33	23	9.2	0.28			
Weighted mean		(112)	4.9	0.22	(85)	4.3	0.17
All studies							
Weighted mean		(367)	4.8	0.28	(305)	6.0	0.33

N = number of subjects, mo = month(s), * = sum of number of subjects presented in parenthesis.

physical activity and weight change is more complex than judged from retrospective, cross-sectional studies.

How much physical activity?

Inadequate amount of physical activity may be one reason why it seems so difficult to find an effect of physical activity on weight maintenance in clinical trials. The weekly amount of prescribed exercise in the randomized trials varied from 80 to 300 min. When the energy expenditure of brisk aerobic exercise is estimated to be 29 kJ/min (7 kcal/min) (58), the above exercise volume corresponds to an increase in weekly energy expenditure by 2300–8800 kJ (560–2100 kcal). However, the adherence to the exercise prescription is much less than 100%, and especially the long-term adherence may be poor (9,53,56,59). Moreover, physical activity in a non-exercising control group is never zero.

Some of the observational studies focusing on weight regain (Table 2) included enough data to estimate energy expenditure of physical activity. McGuire and coworkers (43) reported that weight maintainers expended 1890 kJ/day (450 kcal/day) more than the regainers in physical activity, and that the corresponding difference for energy expenditure during strenuous and moderate activity was 1220 kJ/day (290 kcal). On a weekly level, this means a difference in energy expenditure of 8400 kJ (2000 kcal).

Three of the studies in Table 2 (31,36,40) and an additional study (59) grouped their subjects into three groups according to their weekly physical activity after weight reduction. The estimated difference in energy expenditure of physical activity between the highest and the lowest exercise group was more than 5500 k/week (1300 kcal/week), but less than 8400 kJ/week (2000 kcal/week). The difference in yearly weight regain (high vs. low exercise groups) in the above studies was 5–8 kg. Hence, it seems that an *increase* in energy expenditure of physical activity of approximately 6300–8400 kJ/week (1500–2000 kcal/week) is associated with improved weight maintenance.

This is more than most randomized trials aimed at, and certainly more than the exercisers actually achieved. This was clearly illustrated in the quantitative analysis (Table 5) which suggested that prescribed exercise training augments weight regain by less than 1 kg per year.

Some studies suggest that even a smaller increase (2100–6300 kJ/week or 500–1500 kcal/week) in physical activity also improves weight maintenance, but not as much as a larger increase (31,42,59). In contrast, other results indicate that a moderate increase is not enough (36,40). Schoeller and co-workers (40) conjectured that there is a threshold activity that needs to be reached, before the effects of physical activity on weight change are seen. The strength of the Schoeller and co-workers study (40) was that they used the doubly labelled water method to measure energy expenditure. Therefore, the hypothesis of a threshold is interesting, although somewhat difficult to interpret, at least from the viewpoint of energy balance.

The energy efficiency of physical activity (the amount of activity needed to prevent gain of a given amount of body weight) is another interesting question related to the amount of activity needed to cause a certain difference in weight change. The energy content of fat and protein is 38 kJ/g (9 kcal/g) and 17 kJ/g (4 kcal/g), respectively. Since changes in body composition consist of approximately 75% fat and 25% fat-free mass (out of which 25% is protein) (5,60), a 1-kg difference in body weight change is equal to approximately $[(0.75 \times 38) + (0.25 \times 0.25 \times 17)] =$ 29 MJ (7000 kcal), then a yearly 5–8 kg difference (see above) in weight regain corresponds to an energetic difference of 147–235 MJ/y (35000–56000 kcal/y) or 2800–4200 kJ/week (670–1000 kcal/week). This is much less that the reported difference in physical activity energy expenditure between the high and low exercise groups (6300–8400 kJ/week or 1500–2000 kcal/week). Compensation by decreased physical activity during the non-exercise parts of the day (61) or increased energy intake (62) may at least partly explain the above mathematical discrepancy.

The energy efficiency of physical activity in prospective, observational studies seems to be even worse than the above calculation suggested. The difference in weight gain between groups of large and small amounts of physical activity (of three or four groups) was very consistently 160–170 g/year (11,14,17). All these analyses used follow-up data for grouping. Using multiple regression analyses, three other studies reported that a difference of each weekly hour in vigorous physical activity reduces long-term weight gain by only 40 g/year (13,21,22).

What kind of a physical activity?

Another important aspect related to physical activity is the type of activity. Physical activity – unlike, e.g. smoking – is a very complex behaviour. The complexity leads to several methodological approaches. This, in turn, makes it is difficult to draw conclusions on which dimensions of physical activity are particularly important for a health end-point, such as body weight change (63).

All randomized trials (Tables 3 and 4) used traditional structured training prescription with walking, jogging or ergometer cycling as the modes of exercise. Only King and co-workers (48) encouraged their subjects to also increase daily lifestyle activity. Since the introduction of health-related exercise (64), the interest in lifestyle activity (accumulating several short exercise bouts daily) has increased. Unfortunately, few groups have studied lifestyle activity (42,65) or multiple short-bout exercise (59) on weight change in overweight persons. None of these studies found any statistically significant differences in weight between different kinds of activity.

Studies in Table 1 assessed physical activity with various types of questionnaires. Both studies with data on only vigorous exercise (21,22) found an inverse association between exercise and weight change. However, the different types and intensities of physical activity cannot be compared from these data. The two studies using data on TV watching yielded contradictory results (22,25). Based on these limited data, it seems like TV watching in children would be more closely associated with fatness than in adults (66).

Adherence to increased physical activity

Poor adherence to a given exercise protocol may be one of the main reasons why randomized trials so often fail to find an association between physical activity and weight maintenance (9). On the other hand, retrospective, observational studies actually contrast exercising subjects against truly sedentary subjects. This leads to a much larger difference in energy expenditure between the active and sedentary subjects.

Adherence to increased regular exercise is believed to be particularly problematic among obese subjects (53,59,67,68). Some groups have studied different strategies to increase exercise adherence. Three papers reported that adherence to a home-based exercise-programme is at least as good as a supervised group programme in overweight persons (59,69,70). This is interesting and even surprising, because of the known positive effects of social support on exercise adherence in general (68). Exercise prescribed in multiple short-bouts vs. one continuous daily-bout may or may not improve exercise adherence (59,67). Although one may presume that adherence to lifestyle activity might be easier than to a more fixed exercise regimen, two studies (42,66) found adherence to these two approaches to be equal.

The prescribed amount of physical exercise may have some importance to exercise adherence. Although it seems that a considerable increase in daily energy expenditure is needed, too strenuous a programme may not be the optimal solution. In our study (56), the exercising females were prescribed either a walking programme with a target energy expenditure 4.2 MJ/week (1000 kcal) or another with double the amount of walking (8.4 MJ/week or 2000 kcal). Although the number of steps taken daily at the end of the intervention period was higher in the 8.4 MJ/week group, the 4.2 MJ/week group maintained a higher daily step count at 1 year follow-up. Both groups had returned to their prestudy activity 2 years after the end of the walking intervention phase.

Magnitude and technique of prior weight loss

Does the prior magnitude of weight loss have an influence on the associations between physical activity and weight regain? A very small reduction of body weight (<3 kg) is obviously followed by a small regain in absolute (kg), but not in relative (%) terms (53,54). Since exercise training without dietary changes typically produces only modest weight losses (5,6,10), a comparison in absolute terms against diet-induced weight losses obviously favours physical exercise. However, the focus of the present review was to study the effects of physical exercise in conditions where the exercising subjects and controls (without exercise) had lost approximately the same amount of weight. The available data suggest that the effect of increased physical activity (vs. diet-only treatment) on weight regain was not dependent on the prior weight reduction.

Most of the observational, non-randomized studies (Table 2) found an inverse association between physical activity at follow-up and weight regain. Both studies with no association (28,44) reported a reasonable weight reduction before the follow-up (mean >13 kg). However, among studies reporting an inverse association between physical activity and weight regain, some had remarkable (>20 kg) mean weight reductions (30,31,35–38), whereas others reported modest (<10 kg) weight losses (32,34,42). In randomized trials (Tables 3 and 4), a suggestive positive trend of an exercise programme was observed after a 6–20 kg mean weight reduction. The respective range was 9–16 kg in studies with statistically non-significant results.

Of the 11 studies shown in Tables 3 and 4, four used VLED for weight reduction. Out of these, two (49,56) found at least some positive effects of exercise, and two a suggestive positive trend (47,50). In contrast, only one study without weight reduction by VLED (48) reported that exercise training improved weight maintenance. We are aware that these data do not prove that an exercise programme is more beneficial after VLED than after a conventional, energy-restricted diet. However, we think this is an intriguing hypothesis which calls for more research.

Gender

Because of the heavier body weight of men, one may hypothesize that physical activity has more impact on weight regulation in men than in women. Unfortunately, comparative data on gender, physical activity and weight maintenance are scarce. In prospective, population studies, Haapanen and co-workers (17) and Guo and co-workers (24) found an inverse association between physical activity and weight gain in men, but not in women, thus supporting the above view. In contrast, Klesges and co-workers (12) reported that both work and leisure activity predicted weight loss in women, but not in men. Most clinical trials pooled men and women into the same analyses, or had subjects of only one gender.

The studies presented in Tables 2, 3 and 4 show that the number of women studied (*c.* 3800) is almost double compared to the number of men (*c.* 2100). Without the large number of men in one study (45), the ‘female bias’ would be even more remarkable. Because a potential difference between the genders would have great practical implications, this hypothesis needs more studies.

Measurement techniques

Wareham and Rennie (63) pointed out that the epidemiological studies on physical activity and health are too often only semiquantitative when assessing physical activity. The assessment methods are multiple (see Table 1) but still usually based on questionnaires and more seldom on such equipment as pedometers or accelerometers. It is, therefore, difficult to make any inference on a possible dose–response between physical activity and weight change. An interesting methodological contrast is seen in studies presented in Table 2: Schoeller and co-workers (40) reported that high baseline physical activity predicted less weight regain, while McGuire and co-workers (44) did not show such an association. This difference may be explained by the fact that the former study (40) used doubly labelled water to measure total energy expenditure. This technique is clearly more accurate than the questionnaire used by McGuire and co-workers (44). This single comparison does not prove that the associations between physical activity and weight maintenance would be stronger with better methodology, but there is, clearly, a need for more objective measures of total physical activity.

Improvement in fitness could be considered as an objective indicator for increased physical activity. Unfortunately, the longitudinal data on fitness and weight change were too limited for this study (71). Moreover, while energy balance is affected by the quantity of physical activity, changes in fitness may result from only qualitative (intensity) changes in activity. Therefore, the association between changes in physical activity and fitness are not as self-evident as it first may seem.

Physical activity may attenuate the regain of fat mass, rather than total body weight (72). Unfortunately, among the studies accepted for the present review, only three (40,50,56) reported body composition data during a weight maintenance period. Of these, the two observational reports (40,50) found that both body weight and body fat regain were less in subjects who exercised more after weight reduction. The only randomized study (56) found that a moderate walking programme slightly decreased weight, but not fat regain. More controlled studies are needed to show if and what kind of an activity programme has favourable effects on body composition after weight reduction.

Recommendations

The aim of this paper was to systematically review research data on associations between physical activity and weight gain, with or without prior weight reduction. To reduce the number of potentially confounding variables, we restricted our study to Caucasian (white) adults. The racial restriction was done to control for cross-cultural differences in physical activity pattern, particularly (63). Hence, the results of this review may not be applicable among people outside a western social and cultural background.

We used weight gain and regain as the outcome measures. Another approach in treatment studies would have been to use total weight reduction, i.e. the difference between initial and follow-up body weights (3). By using the 'total weight reduction' approach, Wing (53) found slightly more positive trends for prescribed physical exercise than we did. Evidently, the difference between these two approaches (prevention of weight regain vs. long-term total weight loss) should be kept in mind.

Based on our findings, we feel that the following kinds of studies on physical activity and weight change are needed:

- Controlled trials
- Follow-up periods of adequate duration (>2 years)
- Studies with objective measures of physical activity
- Studies with data on body composition
- Comparison of the effects of physical activity on weight change in men and women
- Comparison of the effects of physical activity on weight change after VLED vs. conventional weight reduction diet
- Studies on the effects of physical activity and weight maintenance during and after long-term weight-reducing drug treatment
- Studies on adherence to increased physical activity

Despite the fact that we do not find the association between physical activity and weight maintenance to be consistent, we would recommend at least lifestyle activity as one part of a healthy lifestyle. We justify this argument by the apparent positive effects of physical activity on dyslipoproteinaemias, insulin sensitivity (73) and physical fitness (72). We conclude that high physical activity is associated with improved maintenance of body weight, but that the effects of a prescribed exercise programme remain very limited.

Acknowledgements

We would like to thank Marlene van Baak for valuable comments and suggestions. The very last sentence of this review was written after a lovely inspiration by Boyd Swinburn.

References

1. International Obesity Task Force (IOTF). Obesity. Preventing and managing the global epidemic. WHO/NUT/NCB/98.1. World Health Organization: Geneva, 1998.
2. Hardeman W, Griffin S, Johnston M, Kinmonth AL, Wareham NJ. Interventions to prevent weight gain: a systematic review of psychological models and behaviour change methods. *Int J Obes* 2000; **24**: 131–143.
3. Jeffery RW, Epstein LH, Wilson GT, Drewnowski A, Stunkard AJ, Wing RR. Long-term maintenance of weight loss: current status. *Health Psychol* 2000; **19**: 5–16.
4. McGuire MT, Wing RR, Hill JO. The prevalence of weight loss maintenance among American adults. *Int J Obes* 1999; **23**: 1314–1319.
5. Garrow JS, Summerbell CD. Meta-analysis: effect of exercise, with or without dieting, on the body composition of overweight subjects. *Eur J Clin Nutr* 1995; **49**: 1–10.
6. National Institutes of Health and National Heart, Lung and Blood Institute. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults. *The Evidence Report Obesity Res* 1998; **6**: (**2**) 51S–209S.
7. Saris WHM. Fit, fat and fat free: the metabolic aspects of weight control. *Int J Obes* 1998; **22**: (**2**) S15–S21.
8. Ravussin E, Gautier J-F. Metabolic predictors of weight gain. *Int J Obes* 1999; **2**: 37–41.
9. Wing RR. Physical activity in the treatment of the adulthood overweight and obesity: current evidence and research issues. *Med Sci Sports Exerc* 1999; **31**: S547–S552.
10. Glenny A-M, O'Meara S, Melville A, Sheldon TA, Wilson C. The treatment and prevention of obesity: a systematic review of the literature. *Int J Obes* 1997; **21**: 715–737.
11. Rissanen AM, Heliovaara M, Knekt P, Reunanen A, Aromaa A. Determinants of weight gain and overweight in adult Finns. *Eur J Clin Nutr* 1991; **45**: 419–430.
12. Klesges RC, Klesges LM, Haddock CK, Eck LH. A longitudinal analysis of the impact of dietary intake and physical

activity on weight change in adults. *Am J Clin Nutr* 1992; **55**: 818–822.
13. Owens JF, Matthews KA, Wing RR, Kuller LH. Can physical activity mitigate the effects of aging in middle-aged women? *Circulation* 1992; **85**: 1265–1270.
14. Williamson DF, Madans J, Anda RF, Kleinman JC, Kahn HS, Byers T. Recreational physical activity and ten-year weight change in a US national cohort. *Int J Obes* 1993; **17**: 279–286.
15. Taylor CB, Jatulis DE, Winkleby MA, Rockhill BJ, Kraemer HC. Effects of life-style on body mass index change. *Epidemiol* 1994; **5**: 599–603.
16. Bild DE, Sholinsky P, Smith DE, Lewis CE, Hardin JM, Burke GL. Correlates and predictors of weight loss in young adults: the CARDIA study. *Int J Obes* 1996; **20**: 47–55.
17. Haapanen N, Miilunpalo S, Pasanen M, Vuori I. Association between leisure time physical activity and 10-year body mass change among working-aged men and women. *Int J Obes* 1997; **21**: 288–296.
18. Heitmann BL, Kaprio J, Harris JR, Rissanen A, Korkeila M, Koskenvuo M. Are genetic determinants of weight gain modified by leisure-time physical activity? A prospective study of Finnish twins. *Am J Clin Nutr* 1997; **66**: 672–678.
19. Kahn HS, Tatham LM, Rodriquez C, Calle EE, Thun MJ, Heath CW. Stable behaviors associated with adults' 10-year change in body mass index and likelihood of gain at the waist. *Am J Public Health* 1997; **87**: 747–754.
20. Parker DR, Gonzalez S, Derby CA, Gans KM, Lasater TM, Carleton RA. Dietary factors in relation to weight change among men and women from two southeastern New England communities. *Int J Obes* 1997; **21**: 103–109.
21. Barefoot JC, Heitmann BL, Helms MJ, Williams RB, Surwit RS, Siegler IC. Symptoms of depression and changes in body weight from adolescent to mid-life. *Int J Obes* 1998; **22**: 688–694.
22. Coakley EH, Rimm EB, Colditz G, Kawachi I, Willett W. Predictors of weight change in men: results from the Health Professionals' follow-up study. *Int J Obes* 1998; **22**: 89–96.
23. French SA, Jeffert RW, Murray D. Is dieting good for you?: Prevalence, duration and associated weight and behaviour changes for specific weight loss strategies over four years in US adults. *Int J Obes* 1999; **23**: 320–327.
24. Guo SS, Zeller C, Chumlea WC, Siervogel RM. Aging, body composition, and lifestyle: the Fels Longitudinal Study. *Am J Clin Nutr* 1999; **70**: 405–411.
25. Crawford DA, Jeffery RW, French SA. Television viewing, physical inactivity and obesity. *Int J Obes* 1999; **23**: 437–440.
26. Fogelholm M, Kujala U, Kaprio J, Sarna S. Predictors of weight change in middle-aged and old men. *Obes Res* 2000; **8**: 367–373.
27. Hoiberg A, Berard S, Watten RH, Caine C. Correlates of weight loss in treatment and at follow-up. *Int J Obes* 1984; **8**: 457–465.
28. Jeffery RW, Bjornson-Benson WM, Rosenthal BS, Lindquist RA, Kurth CL, Johnson SL. Correlates of weight loss and its maintenance over two years at follow-up among middle aged men. *Prev Med* 1984; **13**: 155–168.
29. Kayman S, Bruvold W, Stern JS. Maintenance and relapse after weight loss in women: behavioral aspects. *Am J Clin Nutr* 1990; **52**: 800–807.
30. Holden JH, Darga LL, Olson SM, Stettner DC, Ardito EA, Lucas CP. Long-term follow-up of patients attending a combination very-low calorie diet and behaviour therapy weight loss programme. *Int J Obes* 1992; **16**: 605–613.
31. Hartman WM, Stroud M, Sweet DM, Saxton J. Long-term maintenance of weight loss following supplemented fasting. *Int J Eating Disord* 1993; **14**: 87–93.
32. Lavery MA, Loewy JW. Identifying predictive variables for long-term weight change after participation in a weight loss program. *J Am Diet Assoc* 1993; **93**: 1017–1024.
33. Harris JK, French SA, Jeffery RW, McGovern PG, Wing RR. Dietary and physical activity correlates of long-term weight loss. *Obes Res* 1994; **2**: 307–313.
34. Haus G, Hoerr SL, Mavis B, Robison J. Key modifiable factors in weight maintenance: Fat intake, exercise, and weight cycling. *J Am Diet Assoc* 1994; **94**: 409–413.
35. DePue JD, Clark MM, Ruggiero L, Medeiros ML, Pera V. Maintenance of weight loss: a needs assessment. *Obes Res* 1995; **3**: 241–248.
36. Ewbank PP, Darga LL, Lucas CP. Physical activity as a predictor of weight maintenance in previously obese subjects. *Obes Res* 1995; **3**: 257–263.
37. Walsh MF, Flynn TJA. 54-month evaluation of a popular very low calorie diet program. *J Fam Pract* 1995; **41**: 231–236.
38. Grodstein F, Levine R, Troy L, Spencer T, Colditz GA, Stampfer MJ. Three-year follow-up of participants in a commercial weight loss program. *Arch Intern Med* 1996; **156**: 1302–1306.
39. Blackburn GL, Kanders BS, Lavin PT, Keller SD, Whatley J. The effects of aspartame as a part of a multidisciplinary weight-control program on short- and long-term control of body weight. *Am J Clin Nutr* 1997; **65**: 409–418.
40. Schoeller DA, Shay K, Kushner RF. How much physical activity is needed to minimize weight gain in previously obese women? *Am J Clin Nutr* 1997; **66**: 551–556.
41. Sarlio-Lähteenkorva S, Rissanen A. Weight loss maintenance: Determinants of long-term success. *Eating Weight Disord* 1998; **3**: 131–135.
42. Andersen RE, Wadden TA, Bartlett SJ, Zemel B, Verde TJ, Franckowiak SC. Effects of lifestyle activity vs structured aerobic exercise in obese women. *JAMA* 1999; **281**: 335–340.
43. McGuire MT, Wing RR, Klem ML, Hill JO. Behavioral strategies of individuals who have maintained long-term weight losses. *Obes Res* 1999; **7**: 334–341.
44. McGuire MT, Wing RR, Klem ML, Lang W, Hill JO. What predicts weight regain in a group of successful weight losers? *J Consult Clin Psychol* 1999; **67**: 177–185.
45. Sarlio-Lähteenkorva S, Rissanen A, Kaprio J. A descriptive study of weight loss maintenance: 6 and 15 year follow-up of initially overweight adults. *Int J Obes* 2000; **24**: 116–125.
46. Perri MG, McAdoo WG, McAllister DA, Lauer JB, Yancey DZ. Enhancing the efficacy of behavior therapy for obesity: Effects of aerobic exercise and a multicomponent maintenance program. *J Consult Clin Psychol* 1986; **54**: 670–675.
47. Sikand G, Kondo A, Foreyt JP, Jones PH. Two-year follow-up of patients treated with a very-low-calorie diet and exercise training. *J Am Diet Assoc* 1988; **88**: 487–488.
48. King AC, Frey-Hewitt B, Dreon DM, Wood PD. Diet vs. exercise in weight maintenance. *Arch Intern Med* 1989; **149**: 2741–2746.
49. Pavlou KN, Krey SK, Steffee WP. Exercise as an adjunct to weight loss and maintenance in moderately obese subjects. *Am J Clin Nutr* 1989; **49**: 1115–1123.
50. van Dale D, Saris WHM, ten Hoor F. Weight maintenance and resting metabolic rate 18–40 months after a diet/exercise treatment. *Int J Obes* 1990; **14**: 347–359.
51. Skender ML, Goodrick K, Del Junco DJ, Reeves RS, Darnell L, Gotto AM, Foreyt JP. Comparison of 2-year weight loss trends in behavioral treatments of obesity: diet, exercise, and combination interventions. *J Am Diet Assoc* 1996; **96**: 342–346.
52. Wadden TA, Vogt RA, Foster GD, Anderson DA. Exercise and the maintenance of weight loss: 1-year follow-up of a controlled trial. *J Consult Clin Psychol* 1998; **66**: 429–433.

53. Wing RR, Venditti E, Jakicic JM, Polley BA, Lang W. Lifestyle intervention in overweight individuals with a family history of diabetes. *Diabetes Care* 1998; **21**: 350–359.
54. Perri MG, McAllister D, Gange JJ, Jordan RC, McAdoo WG, Nezu AM. Effects of four maintenance programs on the long-term management of obesity. *J Consult Clin Psychol* 1988; **56**: 529–534.
55. Leermakers EA, Perri MG, Shigaki CL, Fuller PR. Effects of exercise-focused versus weight-focused maintenance programs on the management of obesity. *Addict Behav* 1999; **24**: 219–227.
56. Fogelholm M, Kukkonen-Harjula K, Nenonen A, Pasanen M. Effects of walking training on weight maintenance after a very-low-energy diet in pre-menopausal obese women. A randomized controlled trial. *Arch Int Med* 2000; **160**: 2177–2184.
57. Williamson DF. Dietary intake and physical activity as 'predictors' of weight gain in observational, prospective studies of adults. *Nutr Rev* 1996; **54**: S101–S109.
58. Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, Paffenbarger RS Jr. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 1993; **25**: 71–80.
59. Jakicic JM, Winters C, Lang W, Wing RR. Effects of intermittent exercise and use of home exercise equipment on adherence, weight loss, and fitness in overweight women. *JAMA* 1999; **282**: 1554–1560.
60. Fogelholm GM, Sievänen HT, van Marken Lichtenbelt WD, Westerterp K. Assessment of fat-mass loss during weight reduction in obese women. *Metabolism* 1997; **46**: 968–975.
61. Fogelholm M, Hiilloskorpi H, Laukkanen R, Oja P, Van Marken Lichtenbelt W, Westerterp K. Assessment of energy expenditure in overweight women. *Med Sci Sports Exerc* 1998; **30**: 1191–1197.
62. Tremblay A, Drapeau V. Physical activity and preference for selected macronutrients. *Med Sci Sports Exerc* 1999; **31**: S584–S589.
63. Wareham NJ, Rennie KL. The assessment of physical activity in individuals and populations: why try to be more precise about how physical activity is addressed? *Int J Obes* 1998; **22**: (**2**) S30–S38.
64. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, Kriska A, Leon AS, Marcus BH, Morris J, Paffenbarger Jr. RS, Patrick K, Pollock ML, Rippe JM, Sallis J, Wilmose JH. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995; **273**: 402–407.
65. Dunn AL, Marcus BH, Kampert JB, Garcia ME, Kohl HW, Blair SN. Comparison of lifestyle and structured interventions to increase physical activity and cardiorespiratory fitness. *JAMA* 1999; **281**: 327–334.
66. Robinson TN. Reducing children's television viewing to prevent obesity. *JAMA* 1999; **282**: 1561–1567.
67. Jakicic JM, Wing RR, Butler BA, Robertson RJ. Prescribing exercise in multiple short bouts versus one continuous bout. Effects on adherence, cardiorespiratory fitness, and weight loss in overweight women. *Int J Obes* 1995; **19**: 893–901.
68. Biddle SJH, Fox KR. Motivation for physical activity and weight management. *Int J Obes* 1998; **22**: (**2**) S39–S47.
69. King AC, Haskell WL, Taylor CB, Kraemer HC, DeBusk RF. Group- vs home-based exercise training in healthy older men and women. A community-based clinical trial. *JAMA* 1991; **266**: 1535–1542.
70. Perri MG, Martin AD, Leermakers EA, Sears SF. Effects of group- versus home-based exercise in the treatment of obesity. *J Consult Clin Psychol* 1997; **65**: 278–285.
71. DiPietro L, Kohl HW, Barlow CE, Blair SN. Improvements in cardiorespiratory fitness attenuate age-related weight gain in healthy men and women. The Aerobics Center Longitudinal Study. *Int J Obes* 1998; **22**: 55–62.
72. Pasman WJ, Saris WH, Muls E, Vansant G, Westerterp-Plantenga MS. Effects of exercise training on long-term weight maintenance in weight-reduced men. *Metabolism* 1999; **48**: 15–21.
73. Grundy SM, Blackburn G, Higgins M, Lauer R, Perri MG, Ryan D. Physical activity in the prevention and treatment of obesity and its comorbidities. *Med Sci Sports Exerc* 1999; **31**: S502–S508.

