

Physical activity and its impact on health outcomes. Paper 1: the impact of physical activity on cardiovascular disease and all-cause mortality: an historical perspective

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Summary

The modern scientific study of physical activity began soon after World War II and focused on the epidemic of cardiovascular disease that was beginning to engulf the Western world. Early 'exercise prescriptions' then specified intense bouts of vigorous activity as the most effective way to maintain cardiovascular fitness and 'heart health'. Doctors and other health professionals then grew concerned that progressively fewer individuals were heeding this advice at a time when physical activity from manual work was becoming less common. Evidence was also emerging in the late 1980s that the value of accumulated, moderately intense activities, now of increasing importance during leisure time, may have been overlooked, or at least underplayed, in the prevention of heart disease, diabetes and some cancers. Perhaps in population terms adherence to moderate 'lifestyle' activities would be better than to the earlier vigorous recommendations. Social policy therefore shifted in the United States in 1996; the US Surgeon General's report set out the basic public health message of '30 min of moderate activity five, and preferably all, days of the week'. This recommendation was broadly adopted throughout much of the Western world. How this change in health strategy might impact on unhealthy weight gain and the growing obesity epidemic was given little attention. Here we examine how post-war public health policy in physical activity developed in an attempt primarily to prevent cardiovascular disease. In the following article we examine why too little attention may have been given to unhealthy weight gain and investigate how this may have happened. Then we consider how much physical activity – and of what kind – is needed to prevent unhealthy weight gain.

Keywords: All-cause mortality, cardiovascular disease, development of physical activity guidelines, physical activity.

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Introduction

Current physical activity guidelines are primarily derived from analyses of the impact of physical activity on cardiovascular health. There is now, however, a new emphasis on assessing the dose–response effect of activity on a range of health outcomes in different ethnic groups and environ-

ments. The variables of physical activity itself have to be considered: the mode, frequency, duration and intensity, i.e. the 'dose'. Then the issue is whether individuals of different gender, age and ethnic group vary in their response to any given physical activity 'prescription'.

Other factors have then to be assessed. For example, how important is the underlying level of an individual's fitness

and health? Will an unfit, sedentary person react to the same 'activity dose' as that given to an individual who is more fit or active? Should the dose be administered and evaluated by absolute measures of intensity, duration and frequency and by absolute improvements in health or performance, or in relation to an individual's own level of fitness, perceived level of exertion and percentage improvement from his or her baseline state?

Bouchard and others have recently considered these issues in some detail and clearly demonstrated (1,2) that individuals of the same age, gender and race vary markedly in their physiological responses to the same 'dose' of physical activity. This interindividual heterogeneity is not random but characterized by a familial aggregation of these responses, which has both genetic and environmental components.

The purpose of the present article is not to reiterate these analyses but to examine how current physical activity guidelines were developed almost exclusively for cardiovascular health; however, even here there has been considerable controversy and major shifts in thinking that need to be understood by those involved in obesity. The principal causes of death in obesity are cardiovascular, so experts dealing with physical activity and obesity need to be aware of the data underlying the current advice to engage in brisk walking on five or more days per week. The original studies on physical activity and cardiovascular disease conditioned the whole debate, so an historical perspective is chosen to help understand the real basis for the US-led policy of advocating relatively modest degrees of exercise. Then we consider how to achieve the important goal of reversing the increasing prevalence of obesity that is now of epidemic proportions in both the developed and developing world (3).

Most of the literature to date has concentrated on adult white males in Western societies – and this bias is clearly reflected in the present and other scientific appraisals. The current guidelines for physical activity are based predomi-

nantly on white male adult data. The role of physical activity in the health of children and the elderly requires separate consideration and is not dealt with here.

J. N. Morris, the pioneer: the London busmen studies

The first studies indicating that physical activity might protect against coronary heart disease were conducted by Morris and his colleagues in the years immediately following World War II (4,5). They were attempting to uncover the social factors that might favour the development of a disease which was then emerging in Britain as a new epidemic after the pre-war Depression and poor diets of the working class (6). Morris, with his social health perspective, sought to investigate groups who lived in similar circumstances but differed in their physical activity at work.

He chose the male drivers and conductors of London buses (4) and found an appreciably lower annual total incidence of coronary heart disease among conductors compared with their driver colleagues (1.9 per 1000 year⁻¹ in conductors compared with 2.7 per 1000 year⁻¹ in drivers). When sudden deaths alone were examined, the comparison was even more striking: deaths among drivers were more than twice as high (Fig. 1).

Morris, however, recognized that drivers and conductors might 'self-select' themselves into their different jobs and that the 'mental strains' of driving and conducting were very different. Nevertheless, he broadly concluded: 'that the greater physical activity of "conducting" (on these double-decker vehicles) is a cause of the lower incidence and mortality in the conductors'. Morris and colleagues also assessed physically active postmen who walked the streets delivering mail and more sedentary telephonists and clerks in the postal service. Despite the very different 'mental stress' of transport and postal workers the results were very similar (Fig. 1).

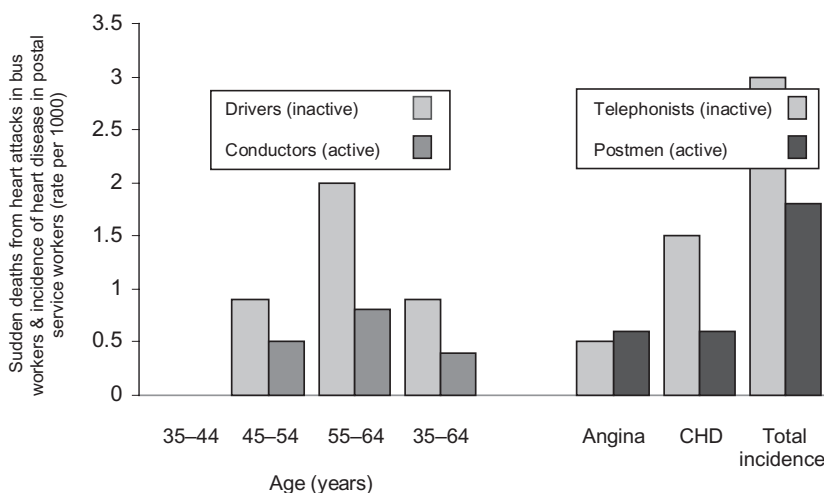


Figure 1 The association between heart disease and physical activity at work among British male workers 1940–1952. Data for drivers and conductors were extracted and collated from ref. 4. Sudden deaths are those occurring within the first three days from 'coronary thrombosis'. Standardized rates for the complete age range (35–64 years) were calculated using the population structure of England and Wales as a basis. Man-years observed were 6668–12 360 (drivers) and 4022–9622 (conductors). There were no reported cases in the 35–44 years age-group. Data for telephonists and postmen were taken from Morris *et al.* (4). GPO male telephonists (25 144 man-years observed) and postmen (160 986 man-years observed) were 35–59 years of age. The incidence of coronary heart disease (CHD) is defined by those dying within three months.

New investigators: railwaymen and longshoremen

US investigators soon began to examine the association between physical activity at work and heart disease. A team lead by Ancel Keys (7) investigated rates of 'arteriosclerotic heart disease' in 1955–56 among US railway workers (40–65 years of age) who were divided into clerks, switchmen and the heaviest workers (known as section men). The section men had a death rate that was just under half (2.8 per 1000) of that of the sedentary clerks (5.7 per 1000).

Ralph Paffenbarger and colleagues then reported on San Francisco longshoremen (dock workers) who had been medically screened in 1951 (8). They used occupational energy cost requirements from existing studies to measure the workloads of each job to rank them in order of energy expenditure. Again, a clear inverse association was seen between workload and deaths from coronary heart disease – except among men older than 65 years of age for whom death rates were equally high, regardless of energy expenditure.

Paffenbarger also demonstrated that physical activity was protective against three major risk factors for heart disease (Fig. 2), with greater benefit being conferred by physical activity on those at greatest risk (8,9). Note the modest effect of excess weight if the men were active, but the marked synergies of risk if heavy men were also inactive.

Morris, again, the pioneer: the switch to sedentary jobs and leisure lifestyles

In 1973, Morris *et al.* presented the 'The Whitehall Study' (10) on recreational or leisure-time physical activities –

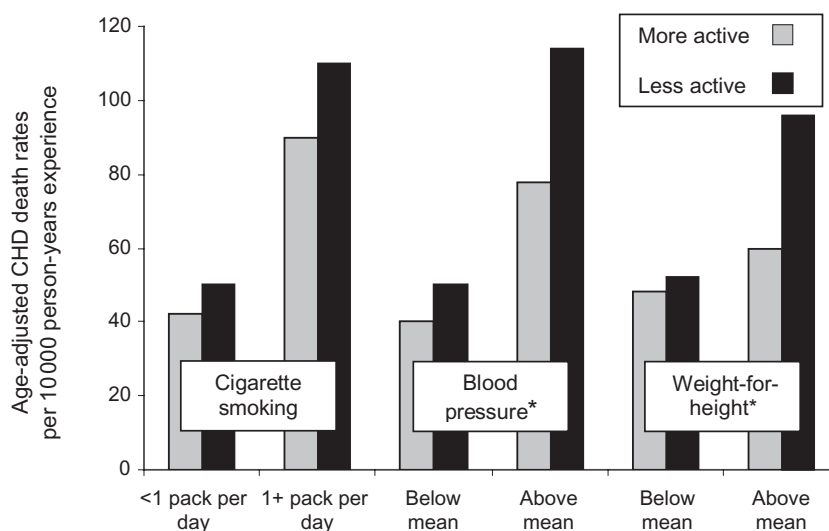
with a distinction between vigorous and non-vigorous exercise – and coronary heart disease. Sixteen-thousand middle-aged (40–64 years of age) male British civil servants were asked retrospectively to report on leisure-time physical activity during a single 48-h period on Friday and Saturday, and also on brisk walking and stair climbing.

Morris considered whether a threshold of vigorous activity, in the form of leisure exercise or physical work, was protective against coronary heart disease. He defined these 'vigorous' intensity activities as 'those likely to reach peaks of energy output of 7.5 kcal min⁻¹, e.g. swimming, hill-climbing, gardening, building work, brisk walking, cycling for longer than 30 min or climbing more than 500 stairs per day'. Morris and his colleagues found no evidence 'of apparent benefit with increasing activity' – by which he meant just the accumulation of more total volume (kcal) of energy expenditure and concluded, emphatically: 'In men recording (some) vigorous exercise, the relative risk of developing coronary (heart) disease was about a third (of) that of comparable men who did not, and in men reporting much of it (vigorous exercise) still less. Lighter exercise and provisional estimates of overall activity showed no such advantage.'

1978–86 – Total energy expenditure: does kcal volume matter too?

Morris *et al.* further supported the 'threshold' hypothesis of vigorous intensity activity as protective against heart disease (11) but Paffenbarger and his colleagues in the US were investigating the protective effect of the accumulated volume of energy expenditure (whatever its intensity) measured in kcal week⁻¹. Nearly 17000 Harvard University males graduating between 1916 and 1950 responded to questionnaires both in the 1960s and in 1972.

Figure 2 The relationship between occupational activity and other risk factors and age-adjusted death rates from coronary heart disease among San Francisco longshoremen. A total of 3263 San Francisco longshoremen (35–64 years of age) were screened for job assignment, cigarette habit, blood pressure level and weight-for-height at the beginning of the study. Death rates from coronary heart disease (CHD) were measured in a 16-year follow-up study with a range of person-years of experience from 18 700 to 25 900. *Represents a *P*-value of <0.05 between the active and less active groups. Data were reproduced from ref. 8 with permission. Copyright © 1970. Massachusetts Medical Society. All rights reserved.



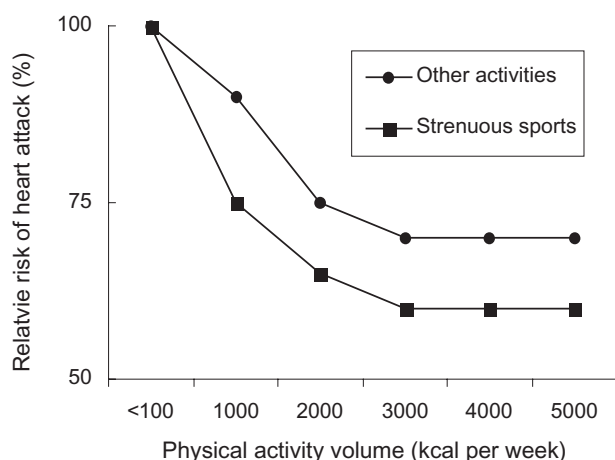


Figure 3 The benefits of total physical activity and of strenuous sports in the protection from a first heart attack in Harvard male graduates. The total volume of the three elements of the physical activity index other than strenuous sports were: light sports, city blocks walked and stairs climbed. The highest risk is taken as the referent (100%) value. Data were reproduced from results presented in ref. 12.

Paffenbarger concluded that the total volume of activities ranked on a 'physical activity index' was increasingly protective against heart attacks up to but not exceeding 3000 kcal week⁻¹. The index ranged from strenuous sports down to everyday activities such as walking and stair climbing. Then Paffenbarger removed strenuous sports from the remaining elements of his physical activity index (Fig. 3).

There seemed to be a greater protective association of strenuous sport than moderate activities, even at the same total volume of expenditure per week. Nevertheless, the benefit of multiple, modest activities was appreciable. Paffenbarger identified a mean total volume of between 2000 and 3000 kcal week⁻¹ as necessary without reference to the mode, frequency, duration and, above all, the intensity of the energy expenditure.

Physical activity and all-cause mortality

Paffenbarger next widened his Harvard Alumni Health Study to investigate all-cause mortality. He also focused on graded levels of total activity with no fewer than eight subdivisions within the range of <500 kcal week⁻¹ to >3500 kcal week⁻¹ (Table 1).

Risk reduction from all forms of activity was apparent in relation to the full range of activities. The difference between almost no and high total physical activity appeared to be greater than whether or not vigorous sports were played. However, Paffenbarger noted that 'participation in vigorous sports would be expected to be most common among alumni expending ≥ 2000 kcal week⁻¹'. We do know that 40% of Harvard Alumni reported their par-

ticipation in at least 1 h of vigorous sport per week – and hence a substantial proportion of the total volume would have been accrued at these higher intensities. But, as presented, the data left Paffenbarger and colleagues unable to ascertain which was more important – the total volume of energy expenditure or 'threshold' vigorous activities.

1987–91: The case for moderate activity begins

In 1989, Blair, together with Paffenbarger and other colleagues, considerably advanced the argument that moderate-intensity activity was a more effective public health tool to reduce all-cause mortality at a time when heart disease was the greatest killer. The design of the investigation was conceived by Dr Kenneth Cooper and became known as The Aerobics Center Longitudinal Study (ACLS), which differed in several important respects from the previous work of Morris and Paffenbarger. First, it included women and second, instead of relying on physical activity questionnaires, measured physical fitness using a treadmill test. Third, the cohort was segregated into quintiles, with the least-fit quintile labelled as the low-fit category. Any subject who could not attain 85% of their expected age-adjusted heart rate on the treadmill at baseline was excluded to reduce the chance of 'finding a spurious inverse relationship between fitness and mortality'. Finally, the cohort was 99% white, relatively well educated (70% college graduates) and from 'middle and upper socio-economic strata'. Hence they were not representative of a cross-section of Americans. However, their blood cholesterol, triglycerides and blood pressure values were similar to those of other large epidemiological studies – and they appeared less non-representative than either the British civil servants (10) or the Harvard Alumni (12).

The techniques of treadmill testing a large cohort and dividing them by degrees of fitness appear to have been pioneered one year earlier by Haskell and colleagues (14). They examined more than 4000 men aged 30–69 years, among whom they established a 'healthy' cohort of more than 3000 who were 'asymptomatic' for heart disease at baseline. Individuals of this cohort were then contacted annually for an average of 8.5 years to establish their survival or death from cardiovascular disease.

Haskell and colleagues found a significant decrease between the least-fit quartile and the next least-fit quartile, as shown in Fig. 4(a).

Clear benefits could be seen from only modest improvements in fitness, but there was also an inverse relationship between all fitness levels and cardiovascular deaths. Indeed, Haskell and his colleagues concluded that: 'In our study, the crude mortality rate was much higher in the least fit quartile as compared with the most fit... these data suggest that the myocardial oxygen supply is enhanced as a result of intense physical training'.

Table 1 The relationship between physical activity and all-cause mortality among Harvard graduates

Physical activity (weekly)	Prevalence (% man-years)	Deaths per 10 000 man-years	Relative risk of death	P-value for trend
Miles walked				0.0009
<3	26.0	78.1	1.00	
3–8	44.2	66.7	0.85	
>9	29.8	61.8	0.79	
Stairs climbed				0.0646
<350	34.4	74.0	1.00	
350–1049	50.0	62.7	0.85	
>1050	15.6	68.0	0.92	
Light sports played (h)*				<0.0001
None	77.0	81.2	1.00	
1–2	6.2	61.4	0.76	
>3	16.8	56.7	0.70	
Vigorous sports played (h)†				<0.0001
None	61.4	75.4	1.00	
1–2	18.4	49.1	0.65	
>3	20.2	55.9	0.74	
Physical activity volume (kcal)‡				<0.0001
<500	15.4	93.7	1.00	
500–999	20.9	73.5	0.78	
1000–1499	15.2	68.2	0.73	
1500–1999	10.4	59.3	0.63	
2000–2499	8.1	57.7	0.62	
2500–2999	6.9	48.5	0.52	
3000–3499	5.0	42.7	0.46	
>3500	18.1	58.4	0.62	

A total of 16 936 Harvard Alumni (35–74 years of age) who reported their freedom from heart disease in 1962 and 1966 were followed up for 12–16 years. All-cause mortality was measured against reported physical activity levels.

*Excludes subjects who played vigorous sports; †with or without light sports play; ‡summation of above activity regimes equated to kilocalories. Data were taken from ref. 13 with permission. Copyright © 1986. Massachusetts Medical Society. All rights reserved.

These findings contrast sharply from the primary observation that has been drawn from the important study of Blair *et al.* (15) on all-cause mortality (Fig. 4b). This appears to show that the greatest fall in deaths occurs between the least-fit quintile and the next least fit. In broad terms, moving from 'sedentary' to just 'moderately active' results in the greatest health benefits. The health benefits from a higher level of fitness appear, in curvilinear fashion, to be modest and reach a plateau, especially in men.

However, the focus on all-cause mortality may have obscured an important observation. Physical activity or fitness may not be significantly protective, for example, against road traffic deaths – indeed, it might arguably increase them. Activity appears also to have only a limited, or no protective effect, against most cancers, with the exception of colon cancer. When we exclude these non-cardiovascular causes of death in Blair and Paffenbarger's data, there appears to be a modest transformation to a more linear relationship between fitness and cardiovascular disease mortality (Fig. 4c). In men, for example, deaths from cardiovascular disease and all causes in the various

fitness quintiles expressed as a percentage of the lowest fitness category (referent) were: for cardiovascular disease, 31.7 and 12.6; and for all causes, 41.1 and 31.7 (quintiles 2–3 and 4–5, respectively) (15). The association between fitness quintile and cardiovascular disease mortality in both men and women therefore is reasonably consistent with the findings of Haskell's team (14), as shown in Fig. 4(a).

The importance of vigorous activity reasserted

In 1990, Morris and his colleagues published their new prospective study of more than 9000 British male civil servants (16), 45–64 years of age and questioned in 1976. Morris again found protection against coronary heart disease only from vigorous aerobic exercise defined quite precisely as having thresholds, or energy peaks, of at least 7.5 kcal min⁻¹, i.e. a work metabolic rate/resting metabolic rate (MET) value of at least 6 and >65% of maximum oxygen uptake (VO₂max). Typical activities included swimming, jogging, badminton, tennis, football, vigorous cycling and field hockey. Walking only qualified as vigorous exer-

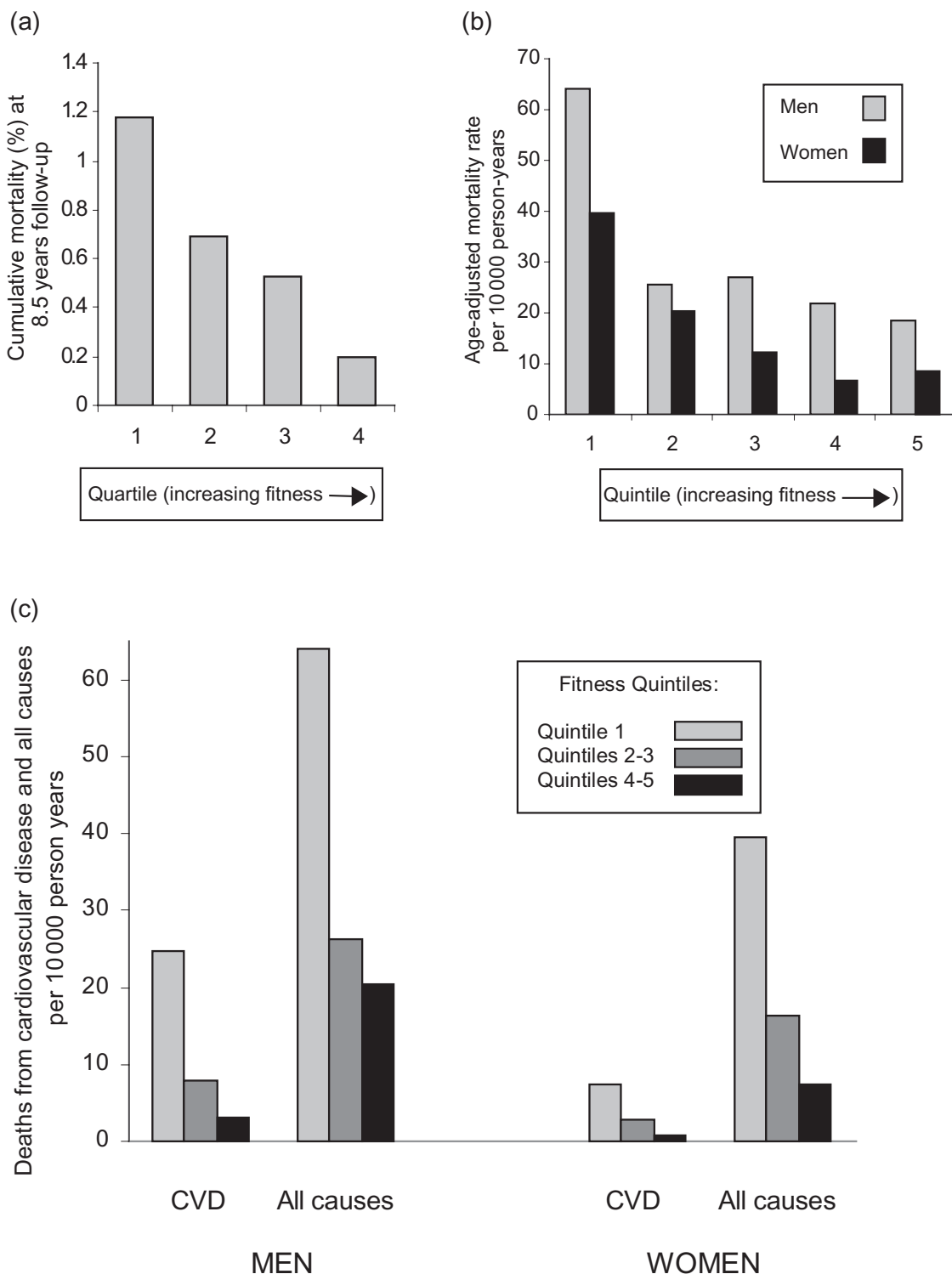


Figure 4 The effect of baseline fitness on (a) cardiovascular death rates, (b) all-cause mortality in healthy subjects and (c) direct comparisons of cardiovascular and total death rates. Data in panel (a) were reproduced from ref. 14 and relate to 3106 healthy, North American men aged 30–69 years from the Lipids Research Clinic Prevalence Survey in 10 US and Canadian centres studied between 1972 and 1976 and followed up annually for an average of 8.5 years. Baseline examinations included conventional coronary risk factors and treadmill testing. The cohort was divided by fitness into quartiles at baseline with the fourth quartile as the most fit. Panel (b) shows data adapted from ref. 15 on 10224 men and 3120 women recruited to the Aerobics Center Longitudinal Study between 1970 and 1981 with an average follow-up period of approximately 8 years. Individuals were treadmill tested at baseline and divided into quintiles (1 low, 5 high). Tests for linear trend in the relative risks per category were in men: slope = -4.5 (95% CI = $-7.1, 1.9$) and in women: -5.5 (95% CI = $-9.2, 1.9$). Data in panel (c), also adapted from ref. 15, show cause-specific death rates by fitness categories in men and women where fitness quintiles have been condensed into three groups. CVD, cardiovascular disease.

cise at very fast speeds of at least 4 mph (6.4 km h⁻¹). Only those reporting weekly vigorous aerobic exercise during their four-week period prior to entry in 1976 showed at follow-up (on average 9.33 years later) substantially less coronary heart disease. Frequency and total volume of energy expenditure from non-vigorous exercise appeared to have no significance but the more vigorous the activity, the greater the benefit ($P < 0.005$ for trend). Morris also recalculated the data to exclude vigorous aerobic exercise from the volume tally and observed 'no gradient in coronary heart disease associated with total profiles of energy expenditure'. Indeed, he noted that the coronary rates in subjects with no vigorous exercise actually increased linearly with energy output from 5.9 (per 1000 man-years) at <2000 kcal week⁻¹ to 7.0 at >3000 kcal week⁻¹.

Morris explained the discrepancy between his British results and those of Blair and Paffenbarger as possibly reflecting different baseline fitness levels with the minority of American men who derived some protective benefit from moderate aerobic exercise perhaps being 'less healthy, active and fit' than his British participants and thus more able to obtain some benefit from less intense exercise. Then, in 1991 Shaper & Wannamethee (17) reported on a prospective study of men selected from age-sex registers from general medical practices in 24 British towns. They too investigated, after an eight-year follow-up, the relationship between physical activity and heart disease. Unusually, they did not exclude men with known heart disease, as Morris, Paffenbarger and Blair had all done previously, and observed an increased risk of heart disease in men who took very frequent vigorous exercise (i.e. more frequently than that defined by Morris). They devised a physical activity index from a range of activities and found, like the US studies, that the total volume of energy expenditure (irrespective of its intensity) did affect the risk of heart attack in these British middle-aged men. When all men who undertook vigorous sport were excluded from the analysis, there was a strong inverse association between the frequency of physical activity and heart disease. Their results accorded therefore with those of Paffenbarger and colleagues.

1992: searching for a consensus

In 1992, Morris, Paffenbarger and Blair appeared to be searching for a consensus that might explain the apparent fundamental differences in their findings.

Morris questioned whether the crucial issue was the fitness of the various cohorts they were studying (18). He noted, for example, that among all the men reporting >2000 kcal week⁻¹ of energy expenditure in the Harvard study of Paffenbarger *et al.* (12), around two-thirds said that they were participating in vigorous sports. But the rest, who did not report vigorous activities, also showed some,

albeit less, advantage from the sheer volume of expenditure. Morris questioned whether the Harvard cohort was basically less active and less fit than his British civil servants and thus capable of benefiting from less intense exercise. 'Comparative physiology studies of American and British men could be rewarding', he suggested. In retrospect, it may be reasonable also to suggest that the British men studied by Shaper in the mid-1980s were now more sedentary than those in Morris' studies in the 1970s. This interval was the time of rapid transition in car ownership and the mechanization of work in Britain and there were very high rates of unemployment and early retirement in middle-aged men. The result was a reduction in physical activity at work and increasingly sedentary lifestyles.

Blair & Paffenbarger 1992: extending the analysis to multiple risk factors

Blair *et al.* (19) then, accepting that the relationship between intensity and volume of energy is complex, examined fitness change and concluded that 'low-intensity activity must be sustained longer than high-intensity activity to have the same effect on improvement in aerobic power'. On the more narrow, but important, issue of blood pressure, Blair *et al.* cited a meta-analysis (20) where moderate-intensity exercise appeared to be just as effective – if not more so – than higher-intensity exercise. It was unclear whether improvements in glycaemic control and lipoprotein profile were a result largely of the cumulative effect of the individual acute bouts of exercise, rather than of a training-mediated change in fitness itself. In 'dose-response' terms, this was the fundamental issue, i.e. whether total volume or the intensity threshold was more important. A more recent review (21) has concluded that moderate-intensity activity is effective in lowering blood pressure – although the evidence that higher-intensity activities were less effective is 'at present inconsistent'. Finally, Blair *et al.* (19) re-examined the major epidemiological studies, including those of Leon *et al.* (22), Morris *et al.* (16), Paffenbarger *et al.* (13), Ekelund *et al.* (14) and Blair *et al.* (15). They concluded that the data supported public health recommendations directed toward the most sedentary and unfit stratum of the population with an emphasis on moderate-intensity physical activity, and that the key factor was total, accumulated energy expenditure.

Blair and Paffenbarger did not appear to consider what impact, if any, this primary change in public health advice (23) from 'vigorous to moderate' intensity activities might have on the prevention of unhealthy weight gain and obesity – even though they drew attention to the importance of obesity as one of the six 'well established' attributable risk factors in cardiovascular disease and death: cigarette smoking, elevated blood cholesterol or blood pressure, high fasting blood glucose, high body mass index

and a history of the early death of a parent from cardiovascular disease.

The intervention studies: is moderate lifestyle activity best?

At this time, two separate investigating groups (24,25) assessed the health impacts of various exercise interventions which varied by intensity and/or setting ('lifestyle vs. structured'). They showed that moderate activity could not deliver the same aerobic fitness as more vigorous activity. However, it could offer improvements in blood pressure and high-density lipoprotein (HDL) cholesterol that rivalled, and sometimes exceeded, those from more vigorous exercise. The first controlled 24-week intervention study (24) compared three walking regimens (strollers, brisk and aerobic) among 59 sedentary women. Women in the most intense regimen (aerobic) enjoyed the greatest improvements in VO_2 max, but the strollers achieved an equally significant increase in HDL cholesterol compared with a control group, as did the aerobic walkers.

The other study (25,26) focused on the importance of adherence to less-controlled exercise programmes extending over longer time-periods. Nearly 400 men and women (50–65 years of age) participated in a two-year randomized trial of three exercise programmes of lower intensity home-based, higher intensity home-based or higher intensity group-based activities. Again, improvements in aerobic fitness did not always correlate with improvements in other aspects of cardiovascular disease risk. Subjects assigned to the lower intensity home-based activities showed the greatest improvement in HDL cholesterol levels, even though adherence to the programme fell dramatically from baseline. Higher-intensity home-based subjects enjoyed greater adherence to the programme and better improvements in VO_2 max – but improvements to their HDL cholesterol

levels were lower. The higher-intensity group-based subjects fared, as a group, least well. They had the smallest improvement in both HDL cholesterol and aerobic fitness – and they also showed the worst adherence record of the three intervention groups.

The exercise intensity categories alter: assessing the response to changes in activity

In 1993, Paffenbarger and colleagues (27) re-emphasized the importance of moderate activity by changing and reducing the number of categories of activities in their latest Harvard Alumni Health analysis. Instead of three (light, mixed, or vigorous) now there were only two 'light sports' defined as an activity requiring fewer than 4.5 METs and 'moderately vigorous' activity requiring ≥ 4.5 METs. This downgraded 'moderately vigorous' activity nevertheless still showed a substantially improved health outcome (as measured by additional years of life) when compared with a mere accumulation (volume) of kcal of energy expenditure achieved without reference to intensity (Fig. 5).

With hindsight, the epidemiological evidence was consistent: an inverse linear relationship between intensity of activity and mortality remained clear, even when the intensity of activities was downgraded. The evidence for the sheer volume of activity – where intensity is not established – was also evident but less strong across all age groups.

In 1995, Blair and colleagues then repeated their treadmill fitness test on a cohort of nearly 10 000 men five years after their initial examination (28) (Fig. 6). The greatest improvement was observed in the relative risk of death from cardiovascular disease in those who changed from 'unfit to fit' (1.00–0.48). If the least fit are removed and quintiles 2–3 (the 'moderately fit') compared with the 'elite' quintiles (4 and 5), the improvement in becoming among the fittest was also strong (1.00–0.72). Remaining in the

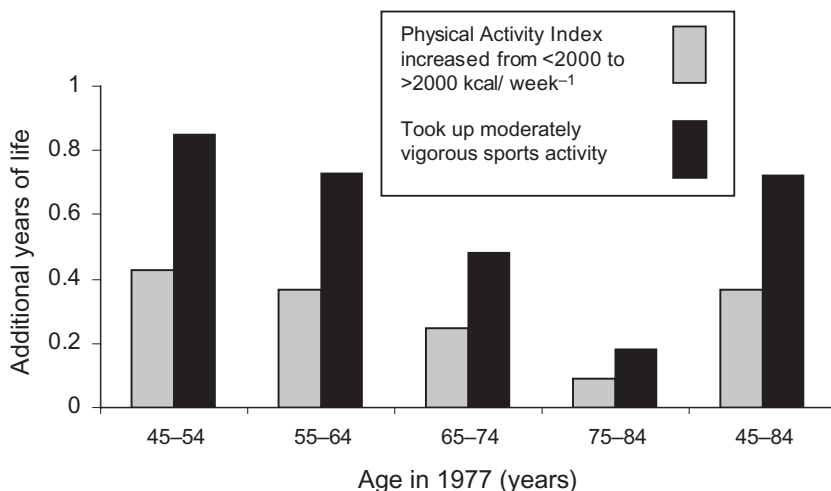
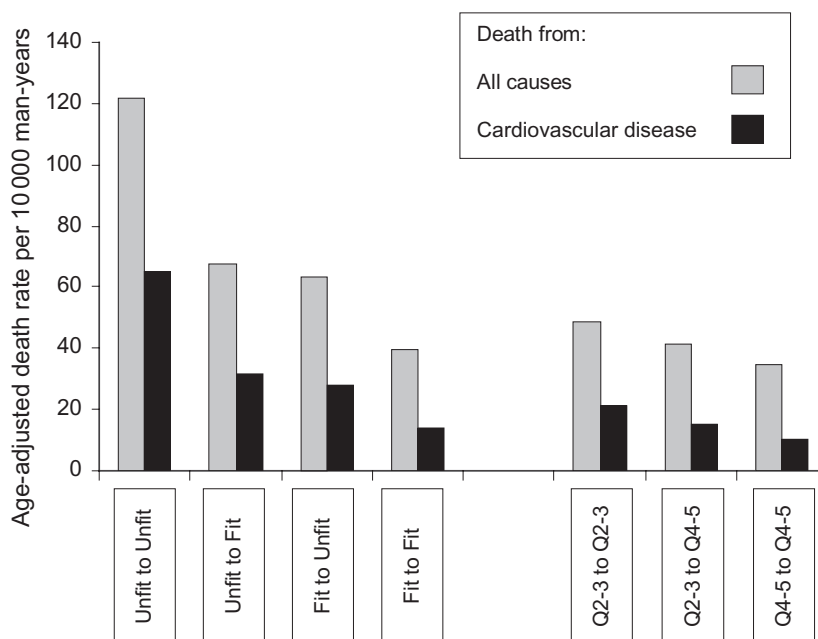


Figure 5 The association between increasing the total volume of physical activity or beginning 'moderately vigorous' sports and added life-years among Harvard graduates. Harvard graduates ($n = 10\,269$; 45–84 years of age) in 1977 who had completed health questionnaires in 1962 or 1966 and again in 1977, were classified according to changes in their reported lifestyle characteristics, including increasing total physical activity volume (kcal week^{-1}) and undertaking moderately vigorous ($\text{METs} \geq 4.5$) sporting activities. Data were taken from ref. 27.

Figure 6 Fitness change as a predictor of all-cause and cardiovascular deaths in men. A total of 9777 US men, aged between 20 and 82 years at baseline, completed at least two health examinations on average 5.1 years apart between 1970 and 1989. Relative risks of death from all causes and cardiovascular disease were compared when the men were assigned to one of four categories: those who did not change fitness status (either fit-to-fit or unfit-to-unfit) and those who did change (unfit-to-fit and fit-to-unfit). The data for the least-fit quintile were then excluded with regrouped fitness quintiles 2–3 and 4–5. Figures above bars are relative risk values for mortality outcomes with the persistently unfit assigned the value of 1.0. Data were adapted from ref. 28.



fittest category (quintiles 4–5) also yielded a relative risk of improvement of 1.00–0.48, even when the moderately fit (quintiles 2–3) are the reference group.

Moderate guidelines become public policy

Evidence was thus mounting that vigorous exercise was not necessarily needed to improve blood pressure and HDL cholesterol levels. Therefore, a ‘public health prescription’ advocating moderate physical activity might best deliver these benefits because a greater number of individuals would probably adhere to such ‘lifestyle’ activities. This view was backed by a special communication led by Russell Pate from the US Centers for Disease Control and Prevention and the American College of Sports Medicine (29). It argued that the then low participation rate in physical activity may have been owing, in part, to the misperception of many people that in order to reap health benefits they were required to engage in vigorous, continuous exercise. They concluded that the scientific evidence clearly demonstrated that regular, moderate-intensity physical activity provided substantial health benefits and therefore formulated the following recommendation which would become public policy throughout most of the world: ‘Every US adult should accumulate 30 min or more of moderate-intensity activity on most, preferably all, days of the week’. They stressed that these moderate activities could be achieved outside formal exercise programmes and they could be enjoyed in accumulated short bouts which fitted into the busy lifestyles of many people.

Moderate physical activity was defined as being performed ‘at an intensity of 3–6 METs (work metabolic

rate/resting metabolic rate) – the equivalent of brisk walking at 3–4 mph (6.4 km h⁻¹) for most healthy adults. Physical activity is closely related to, but distinct from, exercise and physical fitness. They set out the increasing importance of physical activity in a figure (Fig. 7). Once again, the greatest ‘benefit’ could apparently be achieved by moving from category A to reach the ‘moderately active’ volumes and intensity of category B. After that, achieving the highest ‘active’ status of category C apparently achieved relatively little improvement in health benefit.

The authors then examined the ‘protective effects of varying strength between physical activity and risk for several chronic diseases’ – rather than generalized ‘health benefit’ alone. Top of the list was coronary heart disease and hypertension. Also included were type 2 diabetes, osteoporosis, colon cancer, anxiety and depression. However, the avoidance of unhealthy weight gain and obesity was not mentioned.

National Institutes of Health Consensus Panel Report (1996)

In 1996, the US National Institutes of Health (NIH) issued a ‘consensus statement’ on physical activity and cardiovascular health (30). It was drawn up by an independent, 13-member panel who reviewed the evidence of 27 experts. While not a government body, the panel’s report and findings paved the way for the exhaustive US Surgeon General’s report on Physical Activity and Health (31), which was published shortly afterwards. The panel expressed continuing scientific uncertainty about the ‘dose–response’ impact of physical activity on cardiovascular disease and

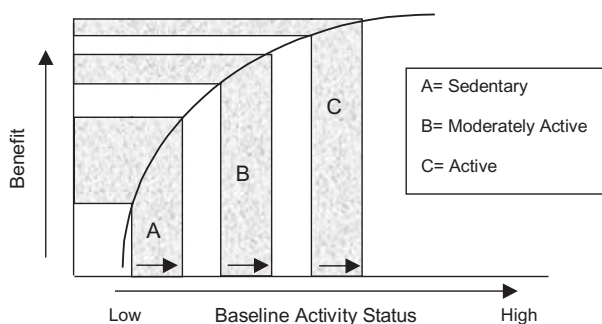


Figure 7 Estimated 'dose-response' curve of health benefits from physical activity. The dose-response curve represents the best estimate of the relationship between physical activity (dose) and health benefit (response). The lower the baseline physical activity status the greater will be the health benefit associated with the given increase in physical activity (arrows A, B and C). Reproduced from ref. 29, with permission.

its risk factors, but recommended a change in the US public health guidelines from vigorous to moderate activity and emphasized that many Americans were currently sedentary and would not attempt to achieve the old 'vigorous' guidelines – so greater adherence could be achieved by an exercise prescription that included everyone and allowed the accumulation of moderate activities designed to suit each individual's interests, preferences and lifestyle.

The panel did consider unhealthy weight gain and obesity as risk factors in cardiovascular disease and noted that public awareness had brought improving trends in other risk factors, such as smoking, high blood pressure and cholesterol levels – but, crucially, not in obesity and physical inactivity. It also highlighted the alarming rise in childhood obesity and the role that its prevention would have in reducing cardiovascular disease in adulthood. The panel further noted that early studies had suggested an inverse relationship between physical activity and body fat – and especially visceral fat – but did not consider whether switching to the moderate guidelines would help or hinder the prevention of unhealthy weight gain and its impact on heart disease.

The US Surgeon General's report on physical activity and health (1996)

The US Surgeon General's exhaustive report drew heavily on the work of Pate *et al.* (29) and the NIH Consensus Panel report. However, it also assembled and dissected an even greater array of scientific evidence. It noted that around 60% of American adults were sedentary or undertook very little recreational physical activity, with few likely to participate in structured or vigorous exercise programmes.

The report sought to give physical activity its proper role in health and disease prevention: 'Physical activity thus

joins the front ranks of essential health objectives, such as sound nutrition, the use of seatbelts, and the prevention of adverse health effects of tobacco'. Its overriding emphasis was on cardiovascular diseases and also concluded that accumulated moderate activity was the best single health prescription to deliver the majority of the benefits to cardiovascular and other health outcomes. However, in the report's forward, Donna E. Shalala, the Secretary of Health and Human Services, stressed that: 'people who are already physically active will benefit even more by increasing the intensity or duration of activity.' Nevertheless, the report endorsed the primary recommendation that US adults should accumulate 30 min of moderately intense activity on five, and preferably all, days of the week.

'Lifestyle' vs. 'structured': investigations continue

After the Surgeon General's Report, Blair and his colleagues (32,33) conducted a randomized trial of greater than 200 sedentary men and women (35–60 years of age) to compare a moderate lifestyle with more vigorous structured activities. Blair and colleagues also recruited different ethnic groups (73% non-Hispanic Caucasian, 14% African-American, 12% Mexican American, and 1% other) and attempted to measure the association between education and adherence, another novel and important issue in public health terms. The participants were offered an exercise regimen of around 1000 kcal week⁻¹, which was either home-based and related to their 'lifestyle', or was carried out at a local fitness centre. The objective was to measure cardiorespiratory fitness and risk factors as well as weight and body fat over a period of 24 months. Both groups were given support from instructors at various times in the investigation. They proposed that a behaviourally based lifestyle physical activity intervention, in which individuals increased their moderate-intensity physical activity as part of their daily routines, would result in higher levels of physical activity and cardiorespiratory fitness at 24 months compared with baseline, and that these levels of physical activity and fitness would be higher in the lifestyle group when compared with a traditional structured fitness centre-based intervention. A secondary aim of this study was to compare changes in cardiovascular disease risk factors from baseline to 24 months and between lifestyle and structured physical activity interventions. The main findings are summarized in Table 2.

Both the lifestyle and structured interventions produced significant and comparable beneficial changes in cardiorespiratory fitness, blood pressure, plasma cholesterol and percentage body fat at 24 months compared with baseline measures. The lifestyle intervention did not, as hypothesized, produce higher levels of physical activity and fitness than the structured intervention. The authors then con-

Table 2 Fitness, other selected outcomes and adherence: comparison of lifestyle and structured interventions in men and women

Outcome	Duration	Lifestyle mean change (95% CI)	<i>P</i> -value	Structured mean change (95% CI)	<i>P</i> -value
VO ₂ max (ml/kg min ⁻¹)	6 months	+1.58 (0.93, 2.22)	0.01	+3.64 (2.98, 4.29)	<0.001
	24 months	+0.77 (0.18, 1.36)		+1.34 (0.72, 1.96)	
Total cholesterol (mMol L ⁻¹)	6 months	-0.2	0.06	-0.3	0.03
	24 months	-0.11 (-0.23, 0.01)		-0.13 (-0.25, -0.01)	
Body fat (%)	6 months	-1.40	0.001	-1.70	<0.001
	24 months	-2.39 (-2.92, -1.85)		-1.85 (-2.41, -1.28)	
Systolic BP (mmHg)	6 months	-3.2	<0.001	-1.8	0.002
	24 months	-3.63 (-5.54, -1.72)		-3.26 (-5.26, -1.25)	
Adherence (MET government guideline level)	6 months	32%		28%	
	24 months	20%		20%	

Data are assembled from refs 32 and 33. Subjects were 116 sedentary men and 119 sedentary women enrolled in a two-year randomized clinical trial ('Project Active') conducted between 1993 and 1997. Cardiorespiratory fitness and cardiovascular disease risk factors were measured at 6 and 24 months after physical activity interventions. Participants assigned to structured exercise engaged in supervised exercise at a well-equipped fitness centre. The lifestyle group participated in a behavioural, group process intervention designed to help them integrate more physical activity into their daily routines. Adherence to government guidelines required 1000 kcal week⁻¹ of physical activity. The statistical *P*-values are for changes from baseline and not for between-group comparisons.

cluded that lifestyle intervention had produced 'significant and comparable' beneficial health outcomes compared with the more vigorous structured intervention and that to achieve greater changes in lipids or weight required, as shown by most other studies, a change in dietary behaviour as well as vigorous exercise. Only 20% of each group managed, at two years, to maintain the government guideline weekly level of energy expenditure of around 1000 kcal, although the authors noted that 21% of lifestyle group and 30% of structured exercise group participants did increase their cardiorespiratory fitness by \geq 10% from baseline (a potentially important threshold in achieving significant improvements in other cardiovascular disease risk factors, including lipoprotein concentrations) (26). Finally, the authors noted the greater relative decline in VO₂max from six months to two years among the structured group. They then suggested that the 'equivalent' success of the lifestyle programme had important public health implications because for 'sedentary persons whose barriers to physical activity may include lack of time, dislike of vigorous exercise, or lack of access to facilities', the results were 'good news'.

This study has been highlighted because it focused on different strategies for improving physical activity and risk factors and was influential in changing experts' views. However, the conclusions were later challenged by Williams (34) who maintained that the subjects in the

structured group of the study were required, after the first six months at the fitness centre, 'to pay a \$495 initiation fee and \$80 per month dues (totalling \$1935), whereas the lifestyle group paid no fees'. This design may have presented a large financial disincentive to maintaining fitness in the structured group.

The persisting debate about moderate or vigorous exercise: the later cohort studies

Paffenbarger and colleagues (35) also examined new data from their Harvard Alumni cohort and again concluded that: 'vigorous activities, but not non-vigorous activities, were associated with longevity'. Nevertheless, they stressed that non-vigorous exercise activities had been shown 'to benefit other aspects of health' – and hence their importance should not be overlooked. However, the total volume of energy expended was only significantly beneficial ($P < 0.001$) when vigorous activities were included in the combined tally. Similarly, when the volume of vigorous activities was shown alone, the same highly significant ($P < 0.001$) linear and inverse trend was seen between increased activity and all-cause mortality. Nevertheless, when volume of energy expenditure from 'non-vigorous' activities alone was plotted, there was no significant trend ($P = 0.87$), regardless of the volume of activity. They concluded that their findings related only to all-cause mortal-

ity, but that even modest exercise had been shown to 'improve, for example, lipid and glucose profiles'. They later (36) again showed that only vigorous activities clearly predicted mortality rates ($P < 0.001$). The best they concluded about moderate activities was that they appeared somewhat beneficial ($P < 0.07$). Light activities had no association with mortality rates ($P = 0.72$).

Blair and colleagues continued, however, to emphasize the benefits of moderate activity and fitness on the basis of their long-running longitudinal studies at the Cooper Institute in Dallas, Texas (37). From cross-sectional analysis of more than 17 000 men and women, they reported a 60% reduction in all-cause mortality between those who were moderately fit (within the second and third quintiles) and the least fit (first quintile). However, the mortality rate only fell thereafter by a further 8% in those in the fittest two quintiles. These results are in keeping with the group's original assertion (15) that the greatest reductions in mortality occur between sedentary and only modestly active people.

Part of the explanation for the seeming discrepancies between the results of Blair and Paffenbarger may lie in the different measurement techniques used (treadmill fitness vs. self-reported activity). However, a more conceivable explanation may lie in the nature of the two cohorts. Blair and colleagues examined both men and women who probably more accurately reflected the American population than a cohort exclusively composed of male Harvard Alumni. Blair's subjects appeared to benefit more in mortality reduction from modest fitness improvement – arguably because their cohort was more sedentary and less fit than the Harvard graduates who may undertake more vigorous sporting activities. This would, of course, be consistent with the observations of Morris about his cohort of British civil servants. If so, this might explain why the Harvard men's vigorous exercise clearly predicted lower mortality rates.

These issues were addressed recently by I.-Min Lee when she focused on a large cohort of older American women (mean age 54 ± 7.0 years) and the association between their physical activity levels and coronary heart disease (38). Nearly 40 000 female health professionals from the United States and Puerto Rico were questioned between 1992 and 1995 about the volume and intensity of their physical activity. A clear, linear and inverse association ($P < 0.001$) was seen between the weekly energy expended on vigorous (METs ≥ 6) recreational activities and their relative risk of coronary heart disease. However, in this cohort of older women a similar trend was also seen in relation to the total volume (kcal week⁻¹) of recreational activities, regardless of their intensity. They considered that the discrepant findings on the value of moderate and vigorous activities reflected a spectrum of responses to physical activity. Among persons with little activity, institution of even light-to-moderate activity would be associated with benefit. Among persons who are more active and fit, vigorous activ-

ity is then needed for additional health benefits. Lee's study participants, in whom light-to-moderate activity was associated with decreased coronary heart disease risk, were relatively inactive.

Thus, it would appear that Morris, Paffenbarger, Blair and Lee were all consistent in their assessments regarding the relationship between physical activity and 'heart health' when examining their own selected cohorts. Vigorous activity is arguably best, especially for those who are already active. Moderate activity, nonetheless, delivers benefits for everyone, and especially to those who are older and most inactive.

Vigorous exertion and the risk of cardiovascular events

More vigorous activity may be a difficult or even an impossible goal for people who are sedentary, older, obese or already handicapped by cardiovascular disease or some other underlying disability that prevents higher intensity activities.

In a recent review, Wannamethee & Shaper (39) again examined the literature in a further attempt to establish whether moderate or vigorous activity is the better exercise prescription to prevent cardiovascular disease. Overall, they concluded that moderate activity – which need not be strenuous or prolonged – was the best prescription. However, the authors' evaluation focused heavily on the literature, which looked at activity prescriptions for the middle aged and elderly. They acknowledged at least four large studies which observed the greatest benefit from vigorous activity, including that of Morris *et al.* (16). However, Wannamethee & Shaper also expressed concern about data which showed that vigorous activity may, at the more extreme ranges of intensity of expenditure, actually increase the risk of coronary heart disease and stroke.

The US Surgeon General's report on physical activity and health (31) had already concluded that sedentary people who suddenly begin vigorous exercise are more at risk from sudden cardiac death than people who exercise regularly – and presumably at levels of duration and intensity to which they are accustomed.

These concerns were again recently studied (at least in men) by a team of investigators (40) who examined the association between vigorous exertion and sudden death from 'cardiac causes' in a 12-year follow-up study of more than 21 000 male doctors within the Physicians' Health Study. Bouts of vigorous exertion were associated with a transient increase in the risk of sudden death, but 'habitual vigorous exercise' diminished the risk which, in absolute terms, was extremely low (1.0 sudden deaths per 1.51 million episodes of exertion). Maron (41) also concluded, on the basis of these data, that the cardiovascular benefits attributable to consistent vigorous exercise as a

primary-prevention strategy for coronary disease in asymptomatic middle-aged and older persons were clear, but this interpretation was disputed in subsequent correspondence to the *New England Journal of Medicine*.

Adherence

In 1999, Dunn and colleagues (33) were forthright in their hypothesis that 'lifestyle activities' were the better 'heart health' exercise prescription for sedentary Americans, compared to more structured and vigorous regimens.

Intuitively, this must have seemed a sensible theory. Both Duncan and King and their colleagues (24–26) had previously observed some excellent results from intervention studies which focused on the value of moderate, lifestyle activities in improving cardiorespiratory risk factors.

Blair and colleagues (33) hypothesized in a similar two-year investigation that levels of 'physical activity and fitness would be higher in the lifestyle group when compared with a traditional structured fitness centre-based intervention'. As they themselves reported, this hypothesis proved unfounded. Physical activity and fitness levels among the lifestyle group were not higher, and adherence levels (as measured by government guidelines) were identical in both groups after two years, at 20% for each cohort. The question therefore remains, in public health terms, which 'activity prescription' – moderate or vigorous – actually delivers better adherence among free living individuals over their lifetimes?

One of the primary reasons for the US Government changing its physical activity guidelines in 1996 was apparently the belief that most Americans simply would not take up and sustain vigorous activities which made them 'sweaty or breathless' (29,30). The evidence for this assertion is, however, open to question. The US Surgeon General's 1996 report (pp 180–181) suggested that only 15% of adult Americans were achieving the old 'vigorous' target of three bouts of exercise for 20 min a week. However, it further estimated that only 22% were achieving (what would become) the new guideline of 30 min of moderate activity on at least five days a week. It might also be reasonably argued that the 'vigorous' exercisers swelled the ranks of those reporting 'moderate' exercise, because, in addition to their vigorous activities, they are more likely to have undertaken more moderate programmes as well. The reverse assertion appears less plausible.

Adherence must also be measured not only by the frequency and duration of compliance but whether, in free-living conditions, individuals actually achieve the intensity of the 'exercise prescription' they have set themselves. For example, the walking habits of 7602 American adults in the state of Michigan during 1996 and 1998 has recently been reported (42). Only 26% of individuals whose only leisure-time physical activity was walking actually reported

that they walked 'briskly' at >3.5 mph (5.6 km h^{-1}) – a speed actually 0.5 mph (0.8 km h^{-1}) slower than the 4 mph (6.4 km h^{-1}) recommended in the US Surgeon General's report. When frequency, duration and intensity were considered together, those even approaching adherence to current moderate guidelines fell steeply. 'Six percent of "only walkers" met the health-related recommendations by walking at least 30 min per session, four or more times per week, at >3.5 mph'. The authors added: 'This proportion was associated significantly with education and income and was higher among higher education and income groups. Finally, a recent major review set out to examine the evidence for the public health belief that moderate activities are a more achievable goal (43). The authors concluded that: 'One of the assumptions underlying recent physical activity recommendations is that lower doses of activity (i.e. intensity and duration) are more enjoyable for the average person, thus leading to higher involvement and adherence rates. However, the veracity of this hypothesis can be questioned, as little is actually known regarding the association between activity doses and affective responses.

Dose–response: the latest evidence

The issues of frequency, duration, intensity and total volume continue to challenge understanding of the impact of physical activity on cardiovascular disease and other health outcomes. The most recent systematic evidence was reviewed and reported at a symposium convened in Ontario in October 2000 to examine these 'dose–responses'. An expert panel was then asked to assess the evidence and to publish its conclusions (44).

First, it concluded that fitness, commonly measured as VO_2max is improved more by high- than low-intensity physical activity. Furthermore, if fitness is an intermediate factor between physical activity and health benefits, then measurement of intensity may be important in assessing the dose–response in health outcomes. It also found some evidence that 'fitness' – or intensity – may be more important than mere physical activity – or volume – in some health outcomes.

However, the consensus panel noted that evidence from most studies available has merely sought to establish the effects (risks and benefits) of regular physical activity – rather than the more precise measurement of the most effective dose (frequency, duration, intensity and total volume) with each health response. In addition, it recognized the considerable individual variability of response in fitness and risk factor responses to any given 'dose' of physical activity.

The panel further noted: 'This is of particular interest because of the current change in recommendation for 30 min of moderate intensity physical activity on most days of the week in place of the previous recommendation that

advocated vigorous-intensity exercise for 20 min continuously three times weekly'. The panel's views can be summarized as follows:

- All-cause mortality. The panel found that it was not possible to assess the impact of the components of exercise volume (intensity and duration) or frequency apart from their contribution to the total volume, which appeared to show a dose–response relationship between physical activity and reduced mortality.
- Cardiovascular disease. The panel found an inverse dose–response with the volume of physical activity, but it was unable to assess the impact of the various 'dose' components.
- Blood pressure and hypertension. Evidence from randomized controlled trials clearly showed that moderate physical activity was effective in reducing blood pressure. Increased intensity did not appear to yield additional benefit.
- Blood lipids. Only a few studies had evaluated the dose–response effects of different exercise intensities on blood lipids, and the consensus panel concluded that these provided conflicting evidence.

Clearly, further research is needed to establish, in population terms at least, the dose–response relationship between the frequency, duration and intensity of physical activity and its impact on cardiovascular disease and its associated risk factors – as well as other health outcomes.

Indeed, when the consensus panel considered the health outcome of prevention of unhealthy weight gain it was very succinct in its judgement: increased levels of physical activity are associated with the prevention of weight gain over time, but the nature of the dose–response relationship is again not clear.

This conclusion is hardly surprising as study of cardiovascular disease has understandably continued to dominate scientific examination of physical activity. In Paper 2 we examine existing evidence, exploring what volumes and intensities of physical activity will probably be necessary, in public health terms, to prevent unhealthy weight gain.

Acknowledgements

While the authors accept all responsibility for remaining errors of fact and judgement, we wish to express our gratitude to the expert panel (listed below) who read, commented upon and corrected the draft report, extending to more than 40 000 words in its original form. This is now set out in www.who.int/diabetes/physical_activity and in summary form in these two papers of the current issue of *Obesity Reviews* which have attempted to explore, both in historical and scientific terms, the impact of physical activity on selected health outcomes with particular reference to heart disease and unhealthy weight gain.

The panel's meticulous analyses have not only made an extremely valuable contribution to the present study but have also highlighted the need for further research on many aspects of this important field of investigation. The expert panel comprised: Steve Blair (USA); Michael Booth (Australia); Claude Bouchard (USA); Anna Ferro-Luzzi (Italy); Mikael Fogelholm (Finland); Ken Fox (UK); Paul Gately (UK); Adrienne Hardman (UK); Bill Haskell (USA); Andrew Hills (Australia); Mark Hargreaves (Australia); Jerry Morris (UK); Neville Owen (Australia); Thomas Robinson (USA); Dale Schoeller (USA); Roy Shephard (Canada); Kate Steinbeck (Australia); Boyd Swinburn (Australia); Ilkka Vouri (Finland); and Klaas Westerterp (the Netherlands).

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