# A history of physical activity, cardiovascular health and longevity: the scientific contributions of Jeremy N Morris, DSc, DPH, FRCP

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Since Hippocrates first advised us more than 2000 years ago that exercise—though not too much of it—was good for health, the epidemiology of physical activity has developed apace with the epidemiological method itself. It was only in the mid-20th century that Professor Jeremy N Morris and his associates used quantitative analyses, which dealt with possible selection and confounding biases, to show that vigorous exercise protects against coronary heart disease (CHD). They began by demonstrating an apparent protection against CHD enjoyed by active conductors compared with sedentary drivers of London double-decker buses. In addition, postmen seemed to be protected against CHD like conductors, as opposed to less active government workers.

The Morris group pursued the matter further, adapting classical infectious disease epidemiology to the new problems of chronic, non-communicable diseases. Realizing that if physical exercise were to be shown to contribute to the prevention of CHD, it would have to be accomplished through study of leisure-time activities, presumably because of a lack of variability in intensities of physical work. Accordingly, they chose typical sedentary middle-management grade men for study, obtained 5-minute logs of their activities over a 2-day period, and followed them for non-fatal and fatal diseases. In a subsequent study, Morris *et al*. queried such executive-grade civil servants by detailed mail-back questionnaires on their health habits and health status. They then followed these men for chronic disease occurrence, as in the earlier survey. By 1973 they had distinguished between 'moderately vigorous' and 'vigorous' exercise. In both of these civil service surveys, they demonstrated strong associations between moderately vigorous or vigorous exercise and CHD occurrence, independent of other associations, in age classes 35–64 years.

In the last 30 years, with modern-day computers, a large number of epidemiological studies have been conducted in both sexes, in different ethnic groups, in broad age classes, in a variety of social groups, and on most continents of the world. These studies have extended and amplified those of the Morris group, thereby helping to solidify the cause-and-effect evidence that exercise protects against heart disease and averts premature mortality.

Keywords Physical activity, coronary heart disease, cardiovascular health, social medicine, exercise science, prospective cohort studies, incidence rates, all-cause mortality, longevity, medical history

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## Early beginnings

Shifts from hunting and gathering to agriculture, and then to industry, have changed physical activity patterns markedly since the *Stone Age*, which has improved mankind's health, vitality, and longevity.[1] The importance of physical activity and physical physique (presumably physical fitness) to health and longevity have long been promulgated through the writings of *The Ancients*. For example, Hippocrates and Galen advised that a lack of physical exercise was detrimental to health, and over-exertion also was unwise. Also, contemporary exercise was more important than remote activity in promoting longevity.[2,3] PT von Hohenheim (usually known as Paracelsus), toward the end of *The Middle Ages*, composed the first monograph ever written on the diseases of an occupational group, namely miners.[4,5] He described the aetiology, pathogenesis, symptomatology, and therapy of specific diseases. Paracelsus also declared that all substances and behaviours (foods, medicine, drink, and presumably exercise) are poisons if taken beyond their dose. From 1690 through 1731, the Italian physician Bernardini Ramazzini, arguably the first epidemiologist, during the early days of *The Enlightenment*, compared and contrasted diseases of various tradesmen, noting that fleet-footed runners, including professional messengers, avoided the occupational health hazards of sedentary tailors and cobblers.[6] He stated: 'Let tailors be advised to take physical exercise at any rate on holidays. Let them make the best use they can of some one day, and so to counteract the harm done by many days of sedentary life'. In 1772, English physician William Heberden described a patient who 'set himself a task of sawing wood for half an hour every day, and was nearly cured'.[7] This may be the first notation of the effect of physical activity on angina pectoris. Also in the late 1770s, Benjamin Franklin who suffered from the gout advised: 'Leave me and I promise faithfully nevermore to play at chess, but to take exercise daily and live temperately'.

With the arrival of *The Industrial Revolution* in England, investigators began to measure the benefits associated with physical activity more objectively, using numerical quantification. In 1843, Dr WA Guy of King's College contrasted mortality rates among sedentary and physically active workers, which favoured the latter.[8] In 1863, Edward Smith found London tailors to be no more healthy relative to physically active tradesmen than Ramazzini had described in Modena 160 years before.[9]

Modern-day exercise science may have originated in the mid-1800s with concern for the health and longevity of oarsmen from Oxford and Cambridge Universities.[10] The belief that vigorous exercise was harmful had not changed since the time of Galen.[11] In contrast, studies of oarsmen from English and eastern US universities late in the 19th and early 20th centuries suggested that the life expectancy of these athletes tended to exceed that of insured or general populations.[12]

In 1915, Dr FC Smith of the US Surgeon General's Office reported on the increasing incidence of degenerative diseases, especially those involving the kidneys, heart, and blood vessels, particularly among those not employed in manual labour.[13] He indicated that 'exercise is necessary for all except those actually and acutely physically ill, at all ages, for both sexes, daily, in amount just short of fatigue'. Then, in about 1920, contemporary occupational studies began to demonstrate that a gradient of increasingly demanding physical jobs was accompanied by a reverse gradient of all-cause death rates, but these associations were not attributed to physical exercise, *per se*.

It was not until after *The Great War*, in 1922, that I Silversten and AW Dahlstrom classified Minnesotans according to contemporary occupational activity and observed that death rates were lower at higher levels of physical activity, and the average age of death increased in gradient fashion with physically more demanding jobs.[14] Yet, the potential for job selection had not been addressed. Men developing chronic diseases might have changed to physically less demanding jobs, thus contributing to the higher death rate among these occupations.

Despite these histories, scientific evidence sufficient to meet *20th Century* standards has been limited. More machines have been devised to carry us about and to do our work, and many of our jobs have been so physically undemanding that we can use computers and robots to do tasks for us while we become increasingly sedentary. The adverse effects of these 'labour saving' developments on public health became increasingly obvious as cardiovascular disease gained ascendancy. An American physician from St Louis, A Hammer, writing and publishing in German in 1878, described the relation of clinical symptoms to resulting pathological findings of myocardial infarction at necropsy of one of his patients.[15,16] While Rudolf Virchow, Edward Jenner, and others had previously described ischaemia in connection with arteriosclerosis, there seemed to be a rising tide of myocardial infarction that was only first clearly defined by Chicago's JB Herrick in 1912.[17] Yet, when OF Hedley reported in 1939 that cardiovascular disease mortality in Philadelphia was higher for white-collar workers than for labourers, the mortality gap was not attributed to their differences in physical activity.[18]

More recently, we have reported on death rates of Harvard College alumni, which declined with increased levels of physical activity (estimated in kcal), and declined also with increased intensity of effort as measured from none, to light, to moderately-vigorous or vigorous sports play.[19] Death rates at any given quantity of physical exercise were lower for men playing moderately intense sports than for less vigorous men. Alumni playing moderately vigorous or more intense sports gained one and one-half years of life expectancy by age 90 compared with less active men.

## Modern-day exercise research

The modern story of exercise and coronary heart disease (CHD) began after *World War II*, in 1949, when Professor Morris and his colleagues began to entertain the notion that deaths from this condition might be less common among men engaged in physically active work than among those in sedentary jobs.[20] Initially, Morris *et al*. found that the apparent protection against CHD enjoyed by active conductors, compared with sedentary drivers of London's double-decker buses, was reproduced in active postmen compared with sedentary telephonists and other government workers. This protection applied in particular against sudden death and other rapidly fatal heart-attack as first presentation of the disease in younger men. Figure 1 describes these findings with expanded data. Morris *et al*. suspected that the larger amounts of total energy expenditure explained the protection, but then they wondered whether the explanation might lie in the difference in nervous strain in these jobs—in line with William Osler's teachings. However, the notion soon was discarded on several counts. For one thing the workers and their trade union officers believed that the conductors' jobs were more emotionally demanding. They had to deal with people all the time, the drivers merely with traffic. On top of that, postal letter carriers seemed to be protected against CHD like conductors as opposed to government clerks, (presumed to be engaged in routine and thus less stressful) work, and to male telephonists, who again were under strain from dealings with

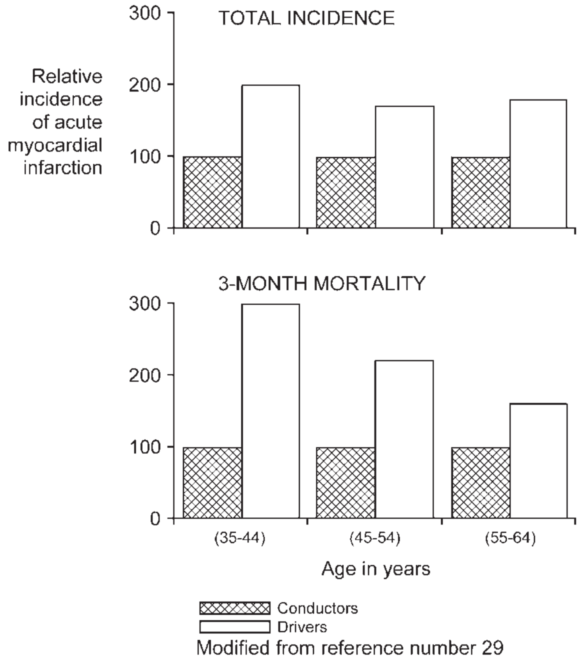


**Figure 1** Age-adjusted relative incidence of acute myocardial infarction in London busmen, 1949–1958

people and much night work. Yet, the coronary experiences of clerks and telephonists were similar. In like fashion, the conductors who would seem to experience far more psychological annoyance than the pedestrian postmen had similar protection against CHD. What now plausibly linked these observations was the difference in total physical activity entailed in these several occupations. Figure 2 presents data that settled the issue for Morris *et al*.

The original finding that conductors and postmen were relatively immune from CHD led to the hypothesis that—men in physically active jobs suffer less coronary-ischaemic-heart disease than comparable men in sedentary jobs; such disease as the active do develop is less severe and strikes at later ages.

This hypothesis was viewed with considerable scepticism by medical scientists and practitioners—the conventional thinking at the time held that CHD resulted from hypertension, hypercholesterolaemia, and obesity, and that physical activity, or lack of it, had nothing to do with the incidence of heart disease.

Nevertheless, the Morris group pressed on, determined to test the possibility that an active lifestyle could help alleviate an increasingly grave public health problem. They pursued the matter further among bus operators and civil servants in three situations: one replicating much of the first; one in quite a different population-at-risk, namely executive-level (high school graduates); and one of a deduction from the hypothesis with another method of study and disease manifestation, again of executive-grade civil servant (desk-bound) workers.

Meanwhile, the adaptation of classical epidemiology to the 'new' problems of chronic non-communicable disease was underway.[21] Coronary heart disease and physical activity of work became a leading programme of the Social Medicine Unit of the Medical Research Council. The hypothesis was tested further, issues of selection and confounding were addressed, and possible biological and social pathways were explored.

## Physical activity of occupation

Analysis of British occupational mortality statistics, adjusted for age, social class, and skill, showed a gradient in CHD death rates, from high to low, that was related to the physical demands of workers' jobs, from 'heavy', through 'intermediate', to 'light'. (The occupational groups of social classes III, IV, and V in the Registrar General's Occupational Mortality Supplement for 1930–1932 had been classified into 'heavy', 'intermediate and doubtful' and 'light' in terms of physical activity involved in the jobs. Two experts in industrial medicine had graded some 1700 different descriptions of occupation independently and then presented findings with an agreed coding.) Heavy exercise represented those who participated in vigorous sports or considerable amounts of cycling, or rated the pace of their regular walking as fast (>4 m.p.h., 6.4 km per hour); moderate exercise was the next lower degree of this vigorous aerobic physical activity; and light exercise all the rest. This gradient of physical demands was evident across social classes I through V, i.e. at each level of skill, thus providing some reassurance that the gradient was not due to drift to light jobs due to ill-health.

A necropsy survey of a national sample began in 1954 under the guidance of the Social Medicine Unit with much support from Britain's academic pathology community.[22] In all, 206 British pathology departments collaborated, close to 90% of the total, using standard methods of recording, as previously described above. The question was put essentially as: 'Do the hearts of middle-aged men vary with the physical work they have done?' Much information was accumulated from the 1200 cases of fatal CHD itself. More interesting, the survey was able to focus on the 3800 cases of other deaths to provide a complementary view of the generality of the population. Taking history of job classification into account, as well as age and social class, the survey found a high prevalence of atheroma throughout

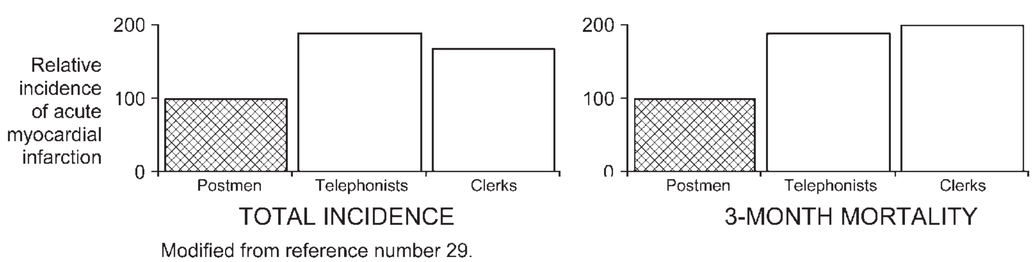


**Figure 2** Age-adjusted relative incidence of acute myocardial infarction in male British civil servants, 1949–1952

the walls of the main coronary arteries in all classes of British men. A significant trend with intensity of occupational physical activity, however, and again in the skilled, part-skilled, and unskilled workers, was seen in the frequency of complete or near-complete occlusion of the coronary lumen. Correspondingly, there was an even stronger trend in ischaemic myocardial fibrosis, the most serious scars of large infarct, in particular. These were four to five times more common in decedents classified as 'light' workers than in decedents classified as 'heavy' workers at 45–59 years of age, and two to three times more common at 60–69 years, repeating the age pattern of the initial incidence studies. All of this was evident in each of the large cause-of-death groups—accidents, infections, cancer, etc.

Clinical records showed that hypertension and hypertensive heart disease were more often found in the 'light' decedents and appeared 10 to 15 years earlier in them than in the 'heavy' workers. Further, the 'light' hypertensives showed a remarkable excess of focal myocardial damage. Perhaps this was the earliest detection of a possible protective effect of physical activity against elevated blood pressure and its complications, for which Morris *et al.* accrued much congruent evidence over the years.

Meanwhile, London Transport Authorities generously offered a population laboratory for sample studies, and the busmen themselves were keenly interested in participating.[23] Thereby, a survey of blood pressure in 687 men, adjusting for age and skinfold thickness, found lower baseline levels in the conductors than the drivers. Moreover, on follow-up, at the same levels of blood pressure, the conductors suffered less CHD than the drivers.

Overall, the conductors were more lightly built than the drivers. Analysis of uniform sizes in a sample of 2270 men demonstrated that, age for age and height for height, trouser waistbands were larger in the drivers, an observation later confirmed by a clinical measurement, and an index of what now is referred to as 'central obesity'. The difference was evident already in the youngest men, i.e. the difference was a characteristic the drivers brought into the job and it then was aggravated during their many working years. Ten-year follow-up of the whole population, however, showed that after taking weight-for-height into account, the rate of sudden death as first clinical manifestation of CHD, for example, was more than twice as high among drivers whatever their physique—slim, average, or 'portly'.[23] (The pattern at 50–64 years of age was less regular, though among the obese there was again slightly more than a twofold excess rate of sudden death among the drivers, independent of weight-for-height.) Dietary sampling found no qualitative differences in the two groups, e.g. in fatty acid composition or fruit and vegetable content. Lipid profiles were more favourable in the conductors, with somewhat lower LDL cholesterol levels (adjusted for age and skinfold thickness), and with strikingly low triglyceride levels.

Despite these findings, much scepticism about the links between physical activity and health persisted among the medical community, which continued to turn their interest to such factors as weight-for-height, hypertension, and lipoprotein profile, while ignoring physical activity.* This scepticism and outright criticism continued, especially in Great Britain, well into the 1980s.[24]

*Authors' note: Protracted controversies can be markedly resistant to new and contrary data.

(It might be noted that busmen worked an 11-day fortnight for 50 weeks a year. The actual shift was 5½ hours, during which drivers on average sat for over 90% of their shift, conductors for less than 10%. The conductors' stair-climbing varied considerably with route, time of day, vehicle, and individual. Conservatively, they climbed 500–750 stairs per working day; this has been compared to brief interval training. Mean heart rate during a working shift in the physiological sample study was 106 per minute in conductors and 91 per minute in drivers.)

## Exercise in leisure time

By the 1960s, it already was evident that if physical activity were to contribute to the prevention of CHD, it would have to be through the exercise taken in leisure time by an increasingly inactive society. Accordingly, Morris and his colleagues selected a new study group to identify personal characteristics and lifestyle elements for prospective follow-up. The study population represented typical office personnel in government service; 18 000 men aged 40–64 in the executive middle-management grade with no history of clinical CHD. This was a stable middle-class group; settled in their habits and homogeneous in education, work, and pay. They were chosen for study after discussions with government and the civil service trades unions. Much effort was put into developing a valid and reproducible assessment of physical activity, which yielded a 5-minute interval log recorded on a Monday for the prior Friday and Saturday, a workday and a free day. A sample group of these men of middle age was divided into thirds by their total activity scores (measured in kilocalories (kcal) per kilogram of body weight per day), which fell from 40 in the most active third to 38 in the intermediate and 33 in the least active third. Measurements above the suprailiac crest showed the largest skinfold differences across activity groups: correspondingly, 9 mm, 10 mm, and 12 mm; the trends in lipids were as expected, the triglycerides in particular.

The hypothesis drawn from the occupational studies stated, simply, that in such 'sedentary' men the frequency of first attacks of CHD would be inversely related to their total amount of physical activity off the job. However, despite detailed analysis of a mountain of data, this hypothesis in the civil servants was flatly refuted.[25,26] 'Vigorous' exercise, defined as apt to reach peaks of 7.5 kcal per min (31.5 kJ per min), alone was related inversely to future CHD incidence. (This was deemed to be 'vigorous' for these men, and enough on average in such a population to induce a training effect; but in the totality of energy expenditure with exercise, 'moderately vigorous' may be a more appropriate term.) Further, the men reporting such energetic regular aerobic exercise—sustained rhythmic dynamic contraction and relaxation of large muscles, as in cycling, swimming, fast walking, badminton, jogging, calisthenics—showed stronger and more consistently lower CHD incidence than comparable men reporting equally energetic and frequent heavy work in the garden, in and around the house, or on the car. The Morris group has speculated that such recreational 'work' is behaviourally more intermittent than the regular aerobic exercise mentioned above, and it entails far less sustained, habitual, and rhythmic large muscle activity besides small muscle and isometric effort. No benefit was apparent in CHD incidence from the large volume of 'non-vigorous' sports that was reported; golf, social dancing, and table-tennis being the most popular.

In the first follow-up survey, from 1968 through 1978, 1138 first clinical episodes of CHD occurred. It was the largest survey up to that pre-computer time in the 8½ years of follow-up. With such numbers it was possible to distinguish the main diagnosed clinical presentations of CHD (in the hospitals of the National Health Service and the government's clinical service): these were sudden death, acute myocardial infarction, angina pectoris, and some coronary insufficiency. This was exemplified by devising a scoring system shown in Table 1. Rates of these conditions were significantly lower in the vigorous aerobic exercisers.[25,26] Overall, total incidence was 3.1% in vigorous exercisers versus 6.9% in the other men; fatal first attacks, 1.1% and 2.9%; non-fatal events, 2.0% and 4.0%, respectively. Of physiological interest, and in contrast to the occupational studies, the mortality advantage of such exercise, as defined, was greatest in the older men. Thus, mortality over the 8½ years in entrants 40–49 years of age reporting the vigorous aerobic exercise was 0.81%, rising only to 1.5% in those of 55–64 years. In the non-exercisers, the corresponding rates increased from 1.7% to 5.0%.

Lower rates of CHD incidence with vigorous exercise similarly were evident in smokers and non-smokers, in the short and tall, in the obese and lean, in those with poor versus those with good health records, and in those with unfavourable versus favourable family histories. (In observations made elsewhere, it has been shown that for some of these characteristics, the inverse association of vigorous exercise [or physical fitness] and CHD was even more striking in the presumed higher risk group than in the lower risk group. In men with a body mass index [BMI] $<$23.0, heart attack rates were 2.4% in vigorous exercisers and 5.2% in those not taking vigorous exercise.[26,27] The relation was even stronger in men with a BMI $\geqslant$28.1, where men reporting vigorous exercise had a heart attack rate of 0.7% and the sedentary men a rate of 8.8%. These results for BMI and exercise are of current interest given the present extreme emphasis on overweight and obesity as a public health problem by the World Health Organization and many national groups.[28–30]) All of this has been interpreted as the so-called 'independent' protective effect of moderately vigorous or vigorous exercise. Moreover, hypertension was less common in the aerobic exercisers, and the hypertensive, while as expected having higher rates, suffered less CHD if they exercised aerobically. In addition, the situation with diabetes was similar.

## A separate test of the new hypothesis

Morris and his colleagues realized that it was undesirable, (a bit extreme, perhaps), *post hoc*, to reformulate a hypothesis, as in fact they had done, then to test it in the same data set. Therefore, a new prospective survey was undertaken in 1976 of 9400 men aged 45–64 years. Again they were civil service executive grade, free of clinical CHD, and followed to 1986 when the oldest attained an age of 73 years. This time the Morris group chose a different method of assessing physical activity: a record of activities over the past 4 weeks as in the national surveys, except for walking and cycling, which pilot tests had shown required only a one-week recall. Vigorous exercise consisted of sports play (swimming was the most popular) twice or more a week, fast regular walking ($\geqslant$4 mph or $\geqslant$6.4 km per h), or much cycling.

The extended study corroborated the earlier findings: the reduction by more than half for CHD incidence, non-fatal and fatal, with moderately vigorous or vigorous exercise.[29] The hypothesis was further refined: sustained, rhythmic, dynamic, aerobic exercise (as in walking $>$4 m.p.h., much cycling, lap swimming) seemed to be protective. Heavy 'recreational work' showed no such relation with CHD incidence (Table 2). At equivalent amounts of total energy expenditure (e.g. kcal per week) aerobic exercise and recreational work would seem different in physiological terms. Perhaps work is less sustained, rhythmic, or dynamic than exercise. In addition, entrants aged 55–64 years who reported the next lower degree of aerobic exercise, e.g. sports play of at least once but not as often as twice a week, recorded CHD rates less than two-thirds the remainder, an indication of dose-response. Entrants aged 45–54 years did not show such an effect (Figure 3). Once again, no relations with CHD incidence were seen with non-vigorous sports; with recreational work (heavy, moderate, or light); or with estimates of total physical activity (Table 3).

The aerobic exercisers had more positive attitudes toward exercise and health, and Morris *et al*. were concerned that these attitudes themselves were associated with lower CHD rates. Again, however, the men with neutral or negative attitudes who nevertheless reported advantageous exercise, experienced similarly lower CHD rates as well. Multivariable analysis,[28] controlling for a range of risk factors (smoking, overweight, subclinical cardiovascular disease, hypertension, diabetes, questionnaire determined angina) and for indicators of health selection in family history and stature, had remarkably little effect on the main finding.

**Table 1** Age-adjusted death rates in per cent from coronary heart disease, 1968–1970 through 1977, by physical activity in leisure time among male executive-grade British civil servants aged 40–64 years at entry

| Physical activity | Rate |
|---|---|
| **Vigorous exercise** | 0.9 |
| **Other men: Non-vigorous 'scores'** | |
| Low third | 2.7 |
| Mid third | 3.1 |
| High third | 2.2 |

Modified from refs 29 and 31.

**Table 2** Age-adjusted incidence rates of coronary heart disease (non-fatal and fatal) in 1000 man-years, 1976 through 1986, by *vigorous* physical activity in leisure-time among male executive-grade British civil servants aged 45–64 at entry

| Sports play[a] | | Recreational work[b] | |
|---|---|---|---|
| Times in past 4 weeks | Rate | Hours in past 4 weeks | Rate |
| 0 | 5.8 | 0 | 5.5 |
| 1–3 | 4.5 | 1–3 | 5.6 |
| 4–7 | 4.1 | 4–7 | 5.5 |
| $\geqslant$8 | 2.1 | 8–11 | 4.2 |
| | | $\geqslant$12 | 5.5 |
| | $P < 0.005$ | | $P > 0.05$ |

[a] Swimming, racket sports, jogging, football (including refereeing).

[b] The heaviest jobs in the garden, in and around the house and on the car: digging, tree felling, building in stone, concreting, rusty repairs.

Modified from refs 29 and 31.

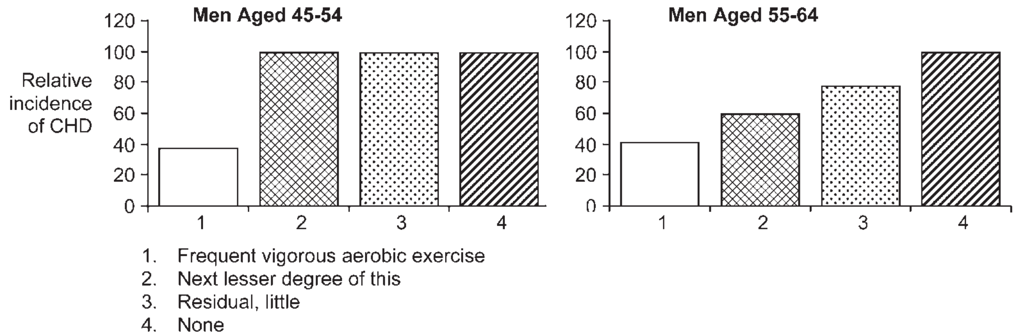


**Figure 3** Age-adjusted relative incidence of coronary heart disease in male executive-grade British civil servants, 1976–1986

**Table 3** Age-adjusted death rates of coronary heart disease in 1000 man-years, 1976 through 1986, by *non-vigorous* physical activity in leisure-time among male executive grade British civil servants aged 60–64 years at entry

| **Normal walking**[a] | | **'Sports play'** | | | | **Recreational work**[c] | | |
|---|---|---|---|---|---|---|---|---|
| | | | Rate | | | | Rate | |
| Hours per day | Rate | Times in past 4 weeks | Long walks[b] | Golf | Ballroom dancing | Hours in past 4 weeks | Gardening | Other |
| <0.5 | 3.9 | 0 | 4.4 | 4.2 | 4.2 | 0 | 4.0 | 3.9 |
| ⩾0.5 | 4.6 | 1–3 | 3.8 | 4.0 | 4.3 | 1–3 | 4.1 | 4.4 |
| | | 4–7 | 4.1 | 5.1 | 5.5 | 4–7 | 6.0 | 3.4 |
| | | ⩾8 | 4.2 | 6.2 | – | 8–11 | 5.7 | 5.2 |
| | | | | | | ⩾12 | 5.7 | 3.9 |

[a] Regular, to and from work, etc.

[b] Of at least an hour, additional to the regular walking, regardless of pace or terrain.

[c] Moderately heavy jobs, e.g. lawn mowing by hand, hedge cutting, bricklaying, painting and decorating.

Modified from refs 29 and 31.

No consistent relations were evident between the kinds of exercise and nervous strain, such as could be measured. Moreover, there was no association of the exercise with taking of prescribed psychotropic drugs.

## Another dimension of the disease

In a sample of 509 of the civil servants who engaged in what was presumed as 'protective' aerobic exercise, 2.9% had definite or probable subclinical ischaemic changes on resting electrocardiogram; this compared with 10.4% of their non-exercising colleagues. Less expected was an excess of ectopic beats in the non-exercisers, 7.1% against 2.9%, which may indicate greater electrical instability. When the exercisers did record higher blood pressures, these were not so strongly associated with electrocardiographic abnormality as in the non-exercisers.

Quite early in the progression of these studies, Morris *et al.* found that total mortality also was lower in men reporting beneficial exercise because there was some reduction in cancer mortality as well as the more substantial fall in CHD and particularly in other cardiovascular diseases with hypertension.[28] A 15-year follow-up of a large sample of the first cohort aged 40–64 years, using Cox model life table analyses, has confirmed this benefit. The survival at 15 years was 89.1% in those reporting vigorous aerobic exercise at entry in contrast with 84.3% in the other men. Cigarette smoking, with its powerful effects on total mortality, was largely independent of exercise and the combined survival rate at 15 years of the exercising non-smokers (at entry) rose to 91.5%, while that of the non-exercising smokers fell to 78.9%. Surprisingly, there were quite small effects from the addition of BMI and a family history of premature mortality into the calculations.

These two characteristics of vigorous exercise and smoking impressed the Morris group all along with their largely independent power. This was most evident in CHD mortality, which was exceedingly low in the exercising non-smokers in both surveys. In the larger first survey, for example, the 1400 office workers aged 40–65 years who engaged in vigorous exercise and did not smoke, registered 12 fatal first 'coronaries' in 12 000 man-years of observation. This can scarcely be considered as part of what is generally known as the 'coronary epidemic'! By contrast, however, their fellows who did not exercise and did smoke recorded about five times as many coronary deaths—recognizably the 'epidemic'.[29,31]

Meanwhile, the main hypothesis was restated by the Morris group to read, that—adequate habitual aerobic exercise of moderate intensity is a substantial protective factor against coronary heart disease in men of middle and early old age whatever their risk levels by other factors.

It is appropriate to record the Report of the English National Fitness Survey here as this large-scale team effort entailed so much work on Professor Morris's part over several years.[32] Even before his foray into exercise science, he advanced the concept that social inequalities alter risk of developing chronic diseases and affect their severity. His forthright and disputatious message was often delivered as a contrary stand to prevailing opinion in a fashion that made no friends in high places.[33] Meanwhile, the Fitness Survey provides new information on the nation's health, physical activity patterns, and several aspects of physiological fitness, together with much medical, social, and psychological data useful to policy makers in promoting exercise. A valid walking 'test' of cardiorespiratory fitness usable by clinicians as well as in public health promotion was implemented, which provided a baseline for measuring progress in the years ahead.[32] At the same time the Survey raised questions of theoretical interest, e.g. regarding the relation of physical activity patterns over the years and its relation to cardiorespiratory fitness.

## Later observations

Since completion of the major studies, Morris *et al*. have focused interest on the efficacy of short bouts of exercise for promoting fitness and preventing CHD. Both of their previous surveys had indicated strongly that intensity, followed by frequency, are more important than duration. Also, only 11% of the spells of beneficial vigorous aerobics sports in the second survey, it is now realized, lasted less than 20 min. This is not surprising; these are health-conscious middle-aged men, going to some trouble habitually to swim, run, etc., twice or more often a week.

Short spells of cycling, on the other hand, were relatively common and apparently associated with lower incidence of CHD. Plausibly, such spells, even of low intensity, if regular, could be enough to induce some training in many sedentary workers. Meanwhile, it was reported that the health advantage these cyclists enjoyed was not due to other exercise being taken, to low BMI, their smoking behaviour, or medical history. Morris and his group are now examining duration of calisthenics to promote fitness and prevent CHD. It already is clear that only if such exercise is very frequent, i.e. ⩾5 days a week, is there an association with lowered risk of CHD.

Despite much effort on both surveys, no harmful effects of exercise have yet been identified in the Morris *et al*. data. Thus, extremes of exercise, e.g. many hours of 'heavy work', have been assessed in combination with hypertension, and adjusting for overweight and smoking, to have no net effect on rates of 'sudden death'. In contrast, other population cohort data suggest that heavy exertion can trigger the onset of CHD, especially in sedentary individuals.[34–36] Data from other middle-aged and elderly cohorts suggest an upturn in rates among the most active as compared with the next lower actives across the age ranges.

## Postscript

Over the past 50 years, a myriad of other populations have been studied for relations among physical activity, physiological fitness, and cardiovascular health. Unique and fundamental contributions of epidemiology have been recognized as a means to understand the causes of cardiovascular diseases, and as procedures to prevent and control them.[37–39] By this means, we have come to know that physical activity protects against the development of CHD, stroke,[40–42] hypertension,[43] obesity,[44–47] non-insulin-dependent diabetes,[48–51] and some cancers.[39,52] Along the way, physical exercise improves functional capacity; enhances mood, thought, and psychological behaviour; and delays the infirmities and disabilities of old age.[30,31] We can say with considerable certainty that postponement of cardiovascular and other chronic diseases through exercise represents cause-and-effect relations via alterations in intermediate mechanisms, not merely expressions of theory or the artifacts of statistical selection.[53]

The host and environmental characteristics that predict altered risk of developing CHD are similar among men and women. Physically active women experience lower CHD rates than inactive women. Even light-to-moderate activity is associated with lower rates. Recent data have suggested that at least one hour of walking a week predicted lower risk, even in women who were otherwise at high risk for CHD, including those who were smokers, overweight, or with high cholesterol levels.[54–57]

Many of these observations on both occupational work and leisure-time recreation, both in primary and secondary prevention of CHD, are based on the lifetime work of Professor Morris, a guiding spirit to good health through modern day exercise science and sports medicine.

## A personal note

We have had the special privilege of working with Professor Morris for many years during his and his colleagues' landmark contributions concerned with exercise to protect against CHD. We know him as imaginative in the design and execution of studies; perceptive, painstaking, and patient in collection of data; precise in the description of findings; logical in inferential reasoning; and bold in the interpretation and presentation of results—even when this brings him into controversy with the authoritarians of the time. Provocative in the face of front bench objections, Professor Morris can respond acerbically and with disdain when his data seem irrefutable.* As a public health protagonist, even a reformer known for his outspoken views, he has worked tirelessly to develop public policies to prevent chronic diseases, to promote good health, and to overcome those social factors that predispose to disease and limit access to health care delivery.

We thank Professor Morris for all of his contributions and wish him well in his current interests of identifying the relative importance of intensity, frequency, and duration of recreational activities to promote good health. We look forward to his designing personal exercise prescriptions and population intervention techniques that will prove useful to clinicians and policy makers in promoting recreational activities for healthful living.

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*Author's interpretation.

KEY MESSAGES

- Over the past half-century Professor Jeremy N Morris and his associates have made substantial epidemiological contributions to our understanding that physical activity protects against the development of coronary heart disease.
- Walking, stair-climbing, recreational activities, and sports play (separately and in combination) lower the risk of specific cardiovascular disease occurrence.
- Physical activity benefits all types—old and young; men and women; hypertensive and normotensive; short and tall; fat and lean; subjects with normal or abnormal lipoprotein profile; and subjects who never smoked cigarettes, ex-smokers, and light, heavy and very heavy smokers.

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