Scand J Work Environ Health 1984;10(6):389-395

<https://doi.org/10.5271/sjweh.2315>

Issue date: Dec 1984

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by [Karvonen MJ](#)

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/6398911

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Physical activity and cardiovascular morbidity

by Martti J Karvonen, MD, PhD

KARVONEN MJ. Physical activity and cardiovascular morbidity. *Scand J Work Environ Health* 10 (1984) 389–395. Habitual physical activity may appear as a determinant of cardiovascular morbidity because of (i) noncausal associations with other risk factors, (ii) an influence on known risk factors, and/or (iii) some, as yet, not defined mechanisms. The associations of physical activity with other life-style variables, such as smoking and plasma low-density lipoproteins, vary both in direction and strength with population, time, and type of physical activity (eg, work versus leisure time). On the other hand physical activity has been shown to cause an increase in plasma high-density lipoproteins and a decrease in plasma triglycerides and insulin and to predict a lower incidence of hypertension. In some multivariate analyses of the incidence of coronary heart disease and strokes, physical activity has evolved as an independent predictor of reduced risk. On the type, intensity, and frequency of physical activity as needed for risk reduction, the results are not fully consistent. For delineating the mechanisms for the independent reduction of risk by physical activity, major investments of further research are still necessary.

Key terms: coronary heart disease, incidence, mortality, occupations, physical activity, prevention, risk factors, work.

Physical activity is widely believed to promote health in general and to be particularly beneficial to the heart and blood vessels. This belief rests on evidence from epidemiologic, clinical, and laboratory studies, but often also on convictions. The present review is primarily concerned with the physical activity of occupational work as a determinant of cardiovascular morbidity. However, studies of off-the-job activity also contribute parallel information and have been consulted.

Physical activity may be noncausally associated with other risk determinants, such as diet, serum cholesterol, smoking, and blood pressure. Such associations need not be similar among all populations. A second possibility is that physical activity exerts a causal influence on an established risk factor, and through it, on risk. A third alternative is that physical activity influences risk through a mechanism independent of the other determinants. This possibility would be indicated in a multivariate analysis by an independent effect of physical activity after adjustment for the other risk determinants included in the study.

Ultimately, the reader has a legitimate right to know where I see the demarcation line between the presently known and unknown, and what hypotheses I would consider fruitful for the planning of further studies.

Morbidity in occupations

Cardiovascular mortality

Records of mortality by occupation are available from a few countries only. The figures from Finland

(36) serve as an illustrative introduction to the problems faced (table 1). The standardized mortality ratio (SMR) for cardiovascular diseases among men shows a wide range among the occupations, from 67 to 131. Of the occupations with heavy physical activity some carry an above-average risk (laborers not elsewhere classified, miners and quarrymen, forestry workers, and unskilled construction workers), while others again seem to be relatively protected (fishermen, construction carpenters, and farmers with 10 ha of land or more). It is worth noting that forest work, an occupation with exceptionally high energy expenditure, has an above-average cardiovascular mortality rate.

A similar analysis in England and Wales (8) gave a somewhat narrower range of variation for cardio-

Table 1. Standardized mortality ratios (SMR) for cardiovascular diseases among men in 1971–1975 (36). Only groups differing statistically significantly ($p < 0.05$) from all employed men are included.

Group	SMR
<i>High mortality</i>	
Shoe and leather workers	131
Laborers not elsewhere classified	129
Miners and quarrymen	122
Wholesale and retail dealers	120
Painters and lacquerers	117
Forest workers	116
Wholesale sales representatives, agents	116
Unskilled construction workers	112
<i>Low mortality</i>	
Farmers with 10 ha of land or more	90
Technical workers	82
Construction carpenters	81
Administrators of establishments and organizations	78
Pedagogical workers	71
Fishermen	70
Religious workers	67

Reprint requests to: Prof MJ Karvonen, I-84060 Pioppi SA, Italy.

vascular mortality among men, from a standardized mortality ratio of 84 to one of 116. The operators of stationary engines, textile workers, and miners and quarrymen were the three occupational groups ranking highest in mortality, while construction workers, paper and printing workers, and electrical and electronic workers had the lowest ratios.

The conclusion can be drawn that occupational differences in cardiovascular mortality exist, but they are not in any obvious way related to the physical activity of work. Moreover the ranking of occupations according to cardiovascular mortality seems to vary in different countries.

Coronary heart disease

Coronary heart disease (CHD) is the major contributor to cardiovascular mortality in most industrial countries. It has a multifactorial etiology. Approximately half of its risk among men, and probably slightly less among women, is determined by age, serum cholesterol, blood pressure, and smoking habits. The other half of the risk may include such life-style variables as physical activity, personality type, and social support as determinants, but this area has not yet been fully mapped out. There is still room for novel work-related risk determinants, waiting to be identified. This possibility was clearly demonstrated in the Whitehall Study of London civil servants. Their lowest rank had 3.6 times the coronary heart disease mortality of the highest one, and after adjustment for age and the known risk factors it still remained 2.6-fold (26).

Several studies have compared the incidence of coronary heart disease in populations contrasting in occupational physical activity. As the epidemic of coronary heart disease was rising, the blue-collar occupations with physical work were lagging behind with a low incidence, but with the advance of the epidemic wave they finally reached and even passed the incidence recorded for persons in sedentary white-collar work. Probably this trend was due to gradual changes in life-style variables such as dietary and smoking habits. However, data on dietary habits, serum cholesterol, and smoking were seldom systematically collected in the past, and hence the explanation for past time trends in the incidence of coronary heart disease remains conjectural.

Some of the early studies chose especially favorable situations for comparing the risk of physically active and sedentary workers. In the collective settlements (kibbutzim) in Israel, both sedentary and physically active workers live in the same environment and eat centrally prepared food in a communal dining room. Brunner et al (6) divided the kibbutzim members into "sedentary" workers who spent at least 80 % of their working time seated, and "non-sedentary" ones; the latter group included industrial and agricultural workers, gardeners, kitchen workers, and kindergarten teachers. The 15-year incidence

of myocardial infarction among the sedentary group was 2.3-fold that of the nonsedentary group. The authors concluded that physical activity at work prevented coronary heart disease. However, physical activity during leisure time may have contributed to prevention, since 20 % of the nonsedentary workers also reported physical leisure-time activities, while the proportion was only 10 % among the sedentary workers.

Morris et al (28), in another pioneering study, used a similar strategy in choosing for comparison two occupations differing in physical activity, ie, the drivers and conductors of London double-decker buses. The incidence of coronary heart disease proved to be lower among the physically active conductors than among the sedentary drivers. However, body type (the drivers were fatter already at recruitment) and the mental stress of driving might have contributed to the difference.

In a prospective cohort study it is possible to include physical activity among several potential determinants recorded for each individual. For the assessment of physical activity, interviews and questionnaires have been used, as well as more or less direct indicators of physical fitness, such as aerobic power (11), vital capacity (7), and resting heart rate (3). Data from such studies can be submitted to a multivariate analysis, with appropriate controls for confounding. A bivariate analysis reveals whether physical activity is associated with risk; a multivariate analysis relates it also to the spectrum of other risk determinants. A recent example of such analyses was carried out by the team of the North-Karelia Project (35). Men with low physical activity at work had a 1.6-fold age-adjusted relative risk of acute myocardial infarction during the seven-year follow-up. They also had higher blood pressure and were fatter than those with high physical activity at work. After adjustment for serum cholesterol, diastolic blood pressure, body mass index, and smoking, the risk ratio was still 1.5. For women the risk ratios were in the same direction, but higher (age-adjusted 2.7 and risk-factor adjusted 2.4). The adjustment for risk factors reduced the predicting power of physical activity only a little and indicated that physical activity must have acted through mechanisms not covered in the study.

The effect of physical activity on morbidity from coronary heart disease has been subjected to multivariate analyses also in several other studies; table 2 lists a number of them. The outcomes have not been all uniform. Differences in outcome may well depend on the population base but may also be due to differences in methods, particularly the procedure used to record exercise habits.

Strokes

The determinants of the incidence of cerebral strokes have been studied less than those of heart attacks, and the role of physical activity has been included

only in very few studies. In the North Karelia investigation (35), low physical activity at work increased the age-adjusted relative risk of stroke 2.0-fold for men and 1.8-fold for women. In contrast, however, among San Francisco longshoremen, the physical activity of work has not been shown to affect the incidence of strokes (29).

Morbidity and leisure-time activity

In an endeavor to study cause-effect relations between physical activity and morbidity, off-the-job activity deserves attention for several reasons. One of these is that individuals in the same occupations can be compared, and thus confounding by occupation can be controlled. This control is particularly important as the nature of some powerful influences of occupation on risk have not yet been identified (26).

Persuasive evidence on the ability of leisure-time physical activity to reduce the risk of heart attacks derives essentially from two studies, one by Morris et al (27) on British executive-grade male civil servants and another by Paffenbarger et al (30) on college alumni in the United States. The two studies concur in indicating that vigorous exercise reduces coronary risk. When the limit between vigorous and nonvigorous was drawn at 7.5 kcal/min (31.5 kJ/min) in the British study, the risk of men with no vigorous exercise proved 2.2-fold in regard to first clinical episodes of coronary heart disease and 2.6-fold in regard to fatal heart attacks. In the American study the age-adjusted relative risk varied from 1.08 to 1.64, depending on the dividing line used for low versus high

physical activity. The risk was reduced more by energy expended in strenuous sports than by the same amount of energy spent in other activities.

Not only the incidence, but also the severity of myocardial infarction might be affected by physical activity habits previous to heart attacks (9). In the Helsinki Myocardial Infarction Register (39) on-the-job physical activity had no influence on survival after the primary heart attack, but off-the-job physical activity — sports or heavy work at least 4 h weekly — was associated with a better prognosis; two years after the attack the survival rate of men showed a 1.4-fold advantage for those physically active in their leisure time.

No protective effect against strokes seems as yet to have been ascribed to leisure-time physical activity (35).

Deaths in connection with physical activity

Physical activity may not always be harmless. In fact, in the Helsinki Myocardial Infarction Register, a history of strenuous activity was elicited for victims of sudden death more often during or immediately before the attack than on the preceding day (17).

In Finland forensic autopsies have been used for an analysis (42) of the occurrence of nonviolent deaths during competitive or conditioning sports or within 24 h thereafter; 97 % of them were cardiovascular and 81 % were due to ischemic heart disease. For men the age-adjusted risk connected with sports exceeded 4.5-fold that during all the time spent otherwise. Vigorous activity showed the highest risk,

Table 2. Multivariate studies on physical activity as an independent determinant of coronary heart disease. (+ = significant risk reduction, — = no significant risk reduction, .. = not reported, . = not applicable)

Author	Population	Physical activity		
		Work	Work + leisure time	Leisure time
<i>Cohort studies</i>				
Brand et al (5)	United States, longshoremen	+	.	..
Garcia-Palmieri et al (10)	Urban Puerto Rico, males	.	+	.
	Rural Puerto Rico, males	.	+	.
Gyntelberg et al (11)	Copenhagen, males	..	.	—
Holme et al (15)	Oslo, males	—	.	+
Kannel & Sorlie (18)	Framingham, males	.	+	.
	Framingham, females	.	—	.
Keys (19)	Seven countries, males	—	.	..
Marmot et al (26)	London, male civil servants	..	.	—
Paffenbarger et al (30)	United States, male college alumni	..	.	+
Rosenman et al (34)	California, males	—	.	—
Salonen et al (35)	East Finland, males	+	.	—
	East Finland, females	+	.	—
Schroll (37)	Denmark, males & females	+ ^a	.	+
Snowdon (40)	United States, 7th day adventists, males	..	+	..
Wilhelmsen et al (43)	Göteborg, males	—	.	—
<i>Case-referent studies</i>				
Hennekens et al (13)	Florida, white males	—	.	+
Magnus et al (25)	Netherlands, males & females	..	.	+
<i>Ecological correlation</i>				
Leaverton & Ingster-Moore (23)	United States, white males	..	+	..
	United States, white females	..	—	..

^a Intermediate levels of physical activity had a lower risk than sedentary and heavy work.

9.0-fold. If, however, the protective effect of physical activity is also considered, it emerges that a reduction of 4–46 % in the long-term risk should be sufficient for striking a balance between the losses and gains.

Mechanisms of protection

Many investigators have published cross-sectional data on associations between physical activity and risk factors with varying results. In those studies in which activity at work and during leisure time has been considered separately, their associations have often differed. The associations of high physical activity during leisure time with blood pressure, total cholesterol, and, particularly, smoking have mostly been in the direction of reducing risk, while just the opposite has applied to high physical activity at work (4, 14, 41). In order to obtain information relevant to cause-effect relations in such a situation, sophisticated analytical approaches and/or experimental studies are necessary. Controlled training experiments are potent tools for demonstrating the effects of physical activity, isolated and uncontaminated by varying sets of confounding influences which are always present in epidemiologic studies of natural populations. But even controlled trials have their limitations.

Blood pressure

Any association between blood pressure and physical activity has been relatively weak in most studies. Endurance sportsmen tend to have a low blood pressure, and this characteristic is retained also after an active sports career (32). This observation has also been extended recently to apply to activity outside competitive sports (31). At the outset of a follow-up middle-aged men with no vigorous sports activity experienced a 1.35-fold incidence of hypertension in comparison to men with vigorous sports activity. Other, independent predictors of hypertension were high body mass index, weight gain since college, and history of parental hypertension.

Some training experiments have shown decreases in blood pressure, but much of this effect has evidently been due to an adaptation to repeated blood pressure measurements. In a controlled training experiment of borderline hypertensive men the resting diastolic pressure decreased equally during four months among the referents and those trained (21). Epidemiologic evidence on long-term effects has thus not yet received full support from experimental studies of short duration.

Blood lipids

In a large population survey in Norway (4), serum cholesterol and triglyceride concentrations decreased regularly with increasing leisure-time physical activi-

ty, more for men than for women, and more for triglycerides than cholesterol, but no corresponding decrease occurred with physical activity at work; in one of the counties, Finnmark, cholesterol even increased with heavy work. On the other hand, with increasing maximum aerobic power, decreasing total cholesterol levels have also been reported (12).

The fraction of cholesterol bound to high-density lipoproteins has again been in the limelight during recent years. Its concentration in blood plasma increases with increasing habitual physical activity all over the total range of activity (22), and high-density lipoprotein is also supposed to reduce the risk of coronary heart disease. A caveat against overdue enthusiasm deserves to be stated however. High-density lipoprotein has shown no association with coronary death rate in two long-term studies, one in Minneapolis in the United States (20) and another in rural Finland (Keys et al, unpublished data), and what is even more disconcerting, high values of high-density lipoprotein cholesterol have predicted increased coronary and total mortality in Moscow and Leningrad (38). It should be remembered that high-density lipoprotein also has other determinants in addition to physical activity.

In regard to serum lipoproteins the verdict of a controlled experiment was that four months of training at an intensity sufficient to increase maximum oxygen intake caused an increase in high-density lipoprotein cholesterol and a decrease of triglycerides (16). With harder and more protracted endurance training the low-density lipoprotein cholesterol may also be slightly reduced, but this result has not been consistent.

Other mechanisms

Some possible mechanisms for protection by physical activity are listed in table 3. Generally their explanatory power has not been sufficiently established in epidemiologic studies so far. Multivariate analyses reveal that differences in the major risk factors explain only a small part, if any, of the differences in risk between sedentary and physically active persons. In the analysis by Salonen et al (35) the lack of physical activity at work was a predictor of myocardial infarctions weaker in strength than age, cholesterol, smoking, and blood pressure. Physical activity during leisure time appears, at its best, to reach a strength of prediction comparable to those of cholesterol, blood pressure, or smoking (27).

Weighing the evidence

Work versus leisure time

Some carefully conducted studies have demonstrated protection against coronary heart disease by physical activity at work and/or during leisure time. The question is how to judge the validity and relevance of

such studies. In order to demonstrate effects in a study of physical activity, the population should be engaged in a wide range of physical activities. Physical activity at work is becoming rare in modern industrial nations. However, physical activity during leisure time is gaining increasing popularity worldwide. The study of the physical fitness of a population sample of men in Minneapolis (24) recently revealed that their aerobic power was positively correlated with physical activity during leisure time, but not at work. Negative correlations with aerobic power were shown by age, body mass index, resting heart rate, cigarette smoking, and consumption of caffeine-containing beverages. Also, in Scandinavia, aerobic power is associated with physical activity during leisure time, not at work (12, 37, 43).

Much of the epidemiologic evidence at hand dates back to an era when vigorous sports were practiced by a few. Its salient finding has been that sedentary life increases coronary risk.

Type of physical activity

A reasonable hypothesis is that, in order to exert a positive effect on cardiovascular health, physical activity ought to produce observable long-term changes in the organism. Dynamic work with large muscle groups requires high energy expenditure and is a potent stimulus for adaptive changes in the cardiovascular system and metabolism and in their neural and endocrine control. Dynamic work has been adopted as the accepted recommendation. This recommendation still leaves a large leeway for a personal choice of leisure-time activities. In most modern occupations, however, machines and rationalization have largely eliminated the elements of vigorous dynamic work.

Threshold intensity

The evidence on the threshold intensity of physical activity is insufficient and partly controversial. Morris et al (27) observed a marked reduction in the risk over 8.5 years, if a 5-min-by-5-min record completed by the subjects over one Friday and Saturday at the beginning of the follow-up contained physical activities which were likely to reach peaks of 7.5 kcal (31.5 kJ)/min, a threshold equivalent to heavy industrial work. Lowering the threshold reduced the power of prediction. The problem is largely tied to the valid measurement of habitual physical activity for long-term studies, and it is not easy to solve. The identification of physiological or biochemical indicators for threshold intensity would be very useful.

Regularity of physical activity

The issue of the regularity of physical activity has been approached in a case-referent study (25); the physical activities of interest were light but sustained, mainly leisure-time walking, cycling, or gardening. A significant reduction of risk of a magnitude similar to

Table 3. Possible mechanisms through which physical activity may reduce the risk of coronary heart disease.

Parameter	Effect
<i>Blood chemistry</i>	
High-density lipoproteins	Increased by physical activity over its entire range
Low-density lipoproteins	Hard endurance training may reduce slightly
Triglycerides	Physical activity decreases
Free fatty acids	Arrhythmogenic; training reduces postexercise peak
Insulin	Habitual activity decreases
<i>Thrombogenesis</i>	
Prostaglandins, platelets	Aerobic exercise and training increase vasodilatory and anti-aggregatory prostacyclin (anaerobic exercise increases proaggregatory thromboxane)
<i>Circulatory parameters</i>	
Strong heart and wide arteries	Endurance training since adolescence
Slow heart rate, hemodynamics	Endurance training reduces beta-receptors, improves hemodynamics; slow heart rate predicts reduced risk
Blood pressure	Vigorous exercise causes long-term lowering

that observed with vigorous exercise (rate ratio = 0.53) was attained also with light physical exercise during leisure time, if the exercise was practiced for more than eight months a year (rate ratio = 0.45). Applying this concept to physical activity at work might still reveal some risk-reducing occupations.

Physical activity and risk factors

All known risk factors have several determinants, many of them variables of life-style. Any observed associations between physical activity and risk factors are thus entirely or partly determined by conditions of life and culture. These determinants should also be considered in study plans.

Independent influence of exercise

The role of the components of cardiovascular fitness in risk reduction has not yet been established. Human training experiments have given valuable information on the spectrum of changes (16, 21, 33), the importance of which may further be tested in epidemiologic research. Maximal aerobic power as a measure of fitness is largely determined by heredity and hence is a poor measure for the training state of the cardiovascular system. The anaerobic threshold as a percentage of the maximal aerobic power would probably give an indication of the training state more relevant to cardiovascular health.

Studies on occupational groups

Life-style is commonly supposed to be related to occupation, but little systematic research in this field has been carried out. Since life-style variables, including physical activity habits, are known to be

potent determinants of health in many ways (1, 2), they should not be overlooked in occupational health research either. Epidemiologic studies with a strong investment in life-style variables, including physical activity, are needed to give a rational foundation for health promotion and the prevention of life-style diseases. The frequently observed unfavorable associations of risk factors with the physical activity of work should be a special challenge for all those concerned.

Physical activity and the occupational health services

With an increasing involvement in work-related diseases the contents of preemployment and periodic examinations are due to be reconsidered. Information on the life-style variables, including physical activity, of individual workers would be helpful in endeavors to assess the contributions of work to risk, and as a base line for prevention.

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