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REVIEW ARTICLE

PHYSICAL ACTIVITY, PHYSICAL FITNESS, AND LONGEVITY

J.Faff
Dept. of Applied Physiology, Military Institute of Hygiene and Epidemiology and Dept. of Physiology, Institute of Sport, Warsaw, Poland

Abstract. It is well documented that both physical fitness and physical activity (PA) are associated with reduction of the mortality from all causes and from cardiovascular diseases. In addition, it has been shown that not only in the young or middle-aged but also in the older people the increase in the level of PA coincides with the reduced morbidity and mortality from a coronary heart disease as well as with the reduced rate of deaths from all causes. It is not clear, however, which of the two - physical fitness or physical activity - reduces the risk of a premature death to a greater extent. Also, no conclusion has been reached about how intensive physical exercising should be to substantially decrease the mortality rate. Some authors suggested that it is moderate to moderately vigorous activity that suffices to beneficially affect longevity. Moreover, moderate activity is safer, especially for the previously sedentary people. However, in case of the healthy subjects adapted to the high intensity training, the beneficial effect of vigorous exercising should not be neglected.

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Physical activity and premature mortality

It is generally agreed that physical activity (PA) and physical fitness are associated with the decreased mortality from all causes and from cardiovascular diseases (CVD). However, in earlier reports beneficial effects of physical activity in terms of increasing the longevity of the athletes could not be clearly demonstrated. For example, Polednak and Damon [76] reported that in 2,090 men who had attended the Harvard University between 1880 and 1916, the life-span of the former elite university athletes were not significantly different from that in their non-athletic counterparts. However, the former minor athletes lived longer than both the elite athletes and the non-athletes. Montoye *et al.* [58] conducted a seven-year follow–up of 628 former athletic award winners at the Michigan State University and their 563 non-athletic classmates. During the observation period, 114 former athletes and 86 control subjects died at the mean age of 62 and 64 years, respectively, the difference being statistically insignificant. Schnohr [83] compared the mortality among 297 male athletic Danish champions with that of the general Danish male population. In the athletes, the ratio of the observed-to-expected deaths equalled to 0.61, 1.08, and 1.02 for those aged between 25 and 49, 50 and 64, and 65 and 80 years, respectively. Thus, among athletic champions younger than 50 years mortality rate was lower than that in the general population but among people above 50 years of age the mortality was not affected by the past athletic activity of the subjects. It is not clear whether the better survival of the former athletic champions less than 50 years old could be related to their intensive physical training or to the fact that from the very beginning the group of the elite athletes consisted mostly of the individuals of excellent health. However, the majority of the published studies conclude that physical activity and physical fitness are inversely related to the mortality and the CVD risk factors. For example, regular joggers exhibit a significantly lower mortality rate than their non-jogging counterparts [84]. In occupational settings, men who expended few calories per workday died from a coronary heart disease more often than their physically more active counterparts [68]. The study of Leon *et al.* [48] conducted on the group of 12,138 middle–aged men, who were followed up for 7 years, indicated that the moderate leisure-time physical activity (LTPA) at 939±222 kJ per day was associated with only 63% of the CVD deaths and 70% of the all-cause deaths compared to the respective mortality rates detected among the low LTPA (309±164 kJ per day) subjects. It is interesting, however, that the mortality risk among the high LTPA subjects (2681±213 kJ) was similar to that in the moderate active group. Eriksen *et al.* [16] found an inverse correlation between physical fitness and both the all-cause and the CVD mortalities. Wei *et al.* [106] demonstrated that low cardiorespiratory fitness was a strong and independent predictor of the CVD and all-cause mortality, comparable with diabetes mellitus and other CVD risk factors. Observations of Paffenbarger *et al.* [71] carried out in a group of 10,269 men for over nine years showed that the subjects with the physical activity index less than 2,000 kcal per week sustained a 25% higher risk of death than their more active counterparts. Lee and Paffenbarger [43] reported that in the group of 13,485 men (mean age 57.5 years) vigorous activities were associated with the significantly lowered mortality rate In fact, lower all-cause mortality rates among the more fit people have been described as well by Blair *et al.* [7].

Compared to men, in women the effect of physical activity and/or physical fitness on the longevity has been studied less frequently. In an early report [32], no association was detected between the level of the activity and the mortality of women. In a group of Finish women occupational activity but not leisure-time physical activity was found to decrease the risk of myocardial infarction [81]. Forest *et al.* [18] reported that while in men physical activity inversely correlated with blood pressure, insulin, total cholesterol, LDL cholesterol, and triacylglycerols, and directly correlated with the HDL cholesterol, no such correlations could be consistently demonstrated in women. It is possible that in some of those studies the physical activity of women, especially housewives and those of the lower socio-economic status, was misclassified. In some other studies, however, the inverse relationship between the leisure time or/and occupational activities and mortality were reported for both men and women. For example, in the study of 1,405 Swedish women aged 38-60 years [49] the relative risk of mortality among the moderately active compared with the least active subjects equalled to 0.28 and 0.56 for the occupational and leisure-time activities, respectively. However, in the most active group of the subjects the risk of death was only slightly reduced compared with that found in the moderately active groups. Blair *et al.* [6] for over 8 years monitored 3,120 women and found that the physically fitter ones lived longer than their less fit counterparts. In women engaged in vigorous leisure-time physical activities the risk of the atherogenic coronary heart disease was less than that detected among the less physically active women [4], the observation which translates into a potential reduction of the coronary heart disease risk by approximately 30%. Kaplan *et al.* [33] described an association between the leisure-time physical activity and the 28-year risk of death from all causes and from a cardiovascular disease in 6,131 adult men and women. Sherman *et al.* [85] for over 16 years monitored 1,404 Framingham women aged 50 to 74 who were categorized into the quartiles based on their physical activity. These authors found that the two more active groups had an overall mortality rate by about 30% lower compared to the two more sedentary groups. Adjustment for cardiac risk factors or exclusion of all the subjects who died during the first six years (to eliminate occult diseases at base line) did not result in any change of the relative risk. It is interesting that in contrast to other studies no association between the activity levels and the cardiovascular morbidity or mortality could be detected in these studies. Moreover, there was a tendency for a higher relative risk of death due to a cardiovascular disease in the most active (1.5) as compared to the least active group of the subjects (1.0). In turn, Manson *et al.* [53] reported a strong graded inverse association between physical activity (up to 35.4 $MET \cdot hr \cdot wk^{-1}$, i.e. 37 $Kcal \cdot kg^{-1} \cdot wk^{-1}$) and the risk of coronary events in women. Ashton *et al.* [4] detected a decrease of a coronary risk factor in the physically active as compared to the inactive women. However, no difference in the beneficial effect of the physical activity was detected between the women who were exercised only once or twice a week and those who were three or more times a week engaged in some form of physical activity. In a retrospective analysis of the data from the Framingham Heart Study, Sherman *et al.* [86] showed that PA significantly reduced mortality from CVD in both men and women. In contrast to males, however, in the females the most active subjects sustained higher mortality rate than those from the moderately active group. On the other hand, several studies have demonstrated beneficial effects of a vigorous activity. For example, in a study conducted on 13,445 Danish women and 17,441 men, the leisure time PA inversely correlated with the all-cause mortality in both the female and male subjects even though a benefit from the physical activity at work was found only in the women [3]**.** Interestingly, even among moderately and highly active persons sport participants experienced only half the mortality rate of non-participants. Increased mortality risk was also reported in the physically inactive adults suffering from a chronic disease as compared to those who, in spite of the chronic ailment, remained physically active [54].

Life expectancy

It can be expected that association between PA and mortality should result in increasing the average life span of the physically active people. In fact, in the study by Pekkanen *et al.* [73] of a cohort of 636 healthy Finish men aged 45-64 years, among those who died in the following 20 years the highly physically active subjects lived 2.1 years longer than their poorly active counterparts. Similar gain (1-2 yrs) in the average life span of the physically active men was reported by Paffenbarger *et al.* [70]. The estimated added life expectancy of alumni aged 45-84 years whose physical activity index increased from less than 2000 kcal to 2000 kcal or more per week equalled to 0.37 years [71]. In another study, Paffenbarger *et al.* [67] estimated that men aged 45-84 years whose physical activity index rose from <1500 Kcal wk^{-1} to 1500 Kcal wk^{-1} could expect to live 1.56 years longer than those who did not increase their PA.

Changes in physical activity

As indicated by several authors, increase in the level of PA is associated with a reduction in the morbidity and mortality from the coronary heart disease as well as with the reduction in the mortality from all causes not only in the young or middle-aged but also in older people**.** In the study of Eriksen *et al.* [16], improvement in physical fitness over time also further reduced the risk of death. According to the data obtained in the Nurses` Health Study [52], sedentary women who became active in their midadulthood or later exhibited a lower risk of coronary events than their counterparts who remained sedentary. In turn, Paffenbarger *et al.* [71] reported that changes in the level of PA, even in men aged 45-74 years, may influence the longevity. In their study, taking to a moderately vigorous activity in sports at the intensity of 4.5 METs (15.75 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$) or more was associated with the 23% lower risk of death compared to those who remained physically inactive. In the more recent work, Paffenbarger *et al.* [67] reported that the relative risk of death in men aged 45-84 years who took to moderately vigorous sports equalled to 0.73 vs. 1.0 detected in those who did not adapt themselves to such games. Similar decrease in the relative risk (0.72) was found in men who by means of walking, stair climbing, and other recreational activities elevated their physical activity to 1500 Kcal or more per week as compared to those who remained less active. In the Copenhagen male study [28], a reduction in the risk of the ischaemic heart disease was detected in subjects aged 40-49 years who increased their PA level during 15 years of the follow-up. However, in subjects aged 50-59 years, a transition from sedentary to physically more active life-style resulted in the increased cardiovascular risk factor (by 1.9) as compared to those who remained sedentary. Lissner *et al.* [49] reported that in women aged 38-60 years a decrease in the physical activity over 6 years significantly increased (by 2.07) the risk of mortality from all causes, although no benefit could be detected from increasing their physical activity. In contrast, in the British Regional Heart Study men who started indulging in at least moderate activity at the average age of 63 years exhibited the significantly lower all-cause mortality than those who reminded sedentary [105].

Physical fitness or physical activity

As indicated above, both physical fitness and physical activity inversely correlate with the CHD**-** and the all cause**-**related mortality rates. On the other hand, physical exercising and the genetic predisposition can both influence physical fitness [8]. Moreover, habitual activity and eagerness to participate in physical exercises can be also genetically determined [74]. Thus, physical fitness correlates with physical activity [15,47,82]. In addition, it has been reported that in young female and male workers the occupational PA is related to physical fitness [96]. Such an association, however, could not be detected in the middle-aged workers [100,101]. It is very difficult, therefore, to conclude whether, in a given population sample, it is physical fitness or physical activity that primarily modifies the longevity. As a result, in many epidemiological studies no attempts were made to discriminate between the beneficial effect on mortality of physical fitness from that of physical activity. For example, Ekelung *et al.* [15] regarded physical fitness as a predictor of the cardiovascular mortality; in that study, however, the level of fitness was closely related to the regular PA reported by the subjects. Similar results were described by Sandwik *et al.* [82]; however, these authors could not detect any independent prognostic value of PA for the mortality from CVD.

To our knowledge, Hein *et al.* [28] were the first to address the question whether it is physical fitness or physical activity that serves as a better predictor of the CVD- and the all causes-related mortality. These authors examined almost 5,000 men without any history of the heart disorders. The subjects were divided into quintiles according to their indirectly measured values of VO_2max and the results of the questionnaire-based assessment of their physical activity at work and at leisure. Mortality of the subjects was recorded over 17 years of the follow-up. Surprisingly, in the sedentary men no association could be detected between the fitness and the mortality. On the other hand, active men from the least fit group exhibited a decreased risk of the CVD and the all-cause mortality compared to their unfit sedentary counterparts. Notably, however, in both the moderately and the highly active men VO_2max also appeared to be a strong predictor of mortality. As indicated by the results of the twin cohort studies, the inverse correlation between PA and premature mortality remained even after the genetic factors and the early childhood experiences had been taken into account. In a study of the Finnish twins [37], the odds for death equalled to 0.66 in the moderately active at leisure subjects and to 0.44 in the highly active ones relative to the odds detected in the sedentary counterparts. In that study, the beneficial effect of PA remained unchanged after the adjustment for other predictors of mortality.

The results of the above described studies suggest that the heredity-associated or the past exercise-induced physical fitness do not affect the tested mortality indices and that the current physical activity-related fitness, at least some part of it, significantly influences the longevity. In contrast, Dvorak *et al.* [14] found that cardiorespiratory fitness exerted greater effect on the cardiovascular disease risk profile than did physical activity. Notably, in that study cardiorespiratory fitness was estimated directly from the results of the graded exercise test and the physical activity-related energy expenditure was determined by the doubly labelled water indirect calorimetry. The examined subjects exhibiting higher VO_2max values regardless of their physical activity showed lower blood levels of fasting insulin, triacylglycerols, total cholesterol, the total-to-HDL cholesterol ratio, and LDL cholesterol as well as the reduced waist circumference than their counterparts with lower VO_2max. The subjects exhibiting high VO_2max but low physical activity displayed the more favourable cardiovascular disease risk profile than individuals with high physical activity but low VO_2max. Moreover, in that study no significant effects (as indicated by the ANOVA analysis) of physical activity on most cardiovascular risk factors except for the LDL cholesterol levels could be detected. In another study of the middle age, healthy women, a graded reduction in the CVD risk score was demonstrated across low, moderate, and high fitness groups of the subjects while no significant association could be found between the CVD_risk score and physical activity [38]. In yet another investigation [96], LTPA and the cardiorespiratory fitness (VO_2 peak) were equally effective in reducing the risk of CVD in men over 65 years of age but in younger, healthy males, higher VO_2 peaks but not higher levels of LTPA were associated with the decreased risk of the cardiovascular morbidity. Likewise, as reported by other investigators [50,93,89], the inverse correlation between some cardiovascular disease risk factors and physical fitness was stronger than that detected between these factors and the physical activity. Andersen and Haraldsdóttir [2] reported that in young Danes the favourable coronary heart disease profile was related to the higher VO_2max but not to the time spent on physical activity. The authors concluded that in young subjects health benefit is related to the VO_2max but not to the PA. According to these authors, the relationship between PA and VO_2max is quite weak and s-shaped rather than linear. Above a certain level of fitness, a great amount of the high-intensity PA is necessary for VO_2max to further increase. On the other hand, numerous authors reported that even low to moderate PA, which can only slightly affect VO_2max, suffices to significantly reduce the CVD- and the all causes-related mortality [22,24,27,47,105]. Additionally, it was demonstrated that the current level of PA is more important in reducing the mortality risk than the past history of exercising [83,86].

It is possible that, in some cases, contradictions between the importance of PA and physical fitness as the health-improving factors can result from the misclassification of these factors. In fact, compared to the level of physical activity that of physical fitness can be defined more precisely (e.g., by estimating the maximal oxygen uptake). However, in the investigations of large population samples, the VO_2max values are most often predicted indirectly from the results of the submaximal exercise the practice that can yield misleading results. On the other hand, as pointed out by Starling *et al.* [94], estimating physical activity based on such commonly employed methods as the detection of the uniaxial motion or various physical activity recall questionnaires can in older subjects underestimate their physical activity-associated energy expenditure by as much as 50%. In addition, in children the questionnaire-based method may lead to a significant overestimation of the expended energy [31]. In turn, middle-aged military officers who earlier in the course of their service had been very active physically markedly underestimated their actual level of PA. [60].

Volume and intensity of physical activity

Lee and Paffenbarger [43] reported that in the group of 13,485 men (mean age 57.5 yrs) minor physical activity (4 METS) was not associated with the reduced mortality rates. In the same study, moderate activity (more than 4 but less than 6 METS) appeared somewhat beneficial but only vigorous activities (6 METS or more) were clearly associated with the reduced mortality rates (1 MET = 3.5 $mlO_2 \cdot min^{-1} \cdot kg^{-1}$). In the study of Paffenbarger *et al.* [70] carried out on 16,936 Harvard alumni aged 35 to 74 years it was found that during 12 to 16 years of the follow-up the death rate declined steadily with the increase in the exercise-induced energy expenditure from less than 500 to 3,500 Kcal per week. In these subjects, the all-cause mortality was by one-fourth to one-third lower among those who expended 2,000 or more Kcal per week compared to those who were less active physically. Interestingly however, among the alumni who expended more than 3,500 Kcal per week the death rate was slightly elevated compared to those who expended 2,500 to 3,500 Kcal per week. Drygas *et al.* [12] reported that the favourable, long-term stabilization of most coronary risk factors in the middle-aged men is attainable when the physical activity-associated energy expenditure exceeds 1,000 Kcal per week. In their study, however, energy expenditure of 2,000 Kcal or more per week was associated with some additional benefits, especially with the increase of the blood HDL cholesterol level. Numerous authors demonstrated beneficial effects of the low to moderate-intensity activities on mortality especially in older nonathletes. In the Finish cohort of 1,072 men aged 35-63 years the leisure PA-related weekly energy expenditure of <800 Kcal was associated with the increased risk of both the all-cause (by 2.74) and the CVD-associated (by 3.58) mortality as compared to the most physically active subjects whose weekly energy expenditure amounted to at least 2,100 Kcal. However, mortality rate among the subjects whose energy expenditure ranged from 800 to 1,500 Kcal was comparable to that detected among the most active men [22]. Similar results were obtained by Leon *et al.* [48] who reported that moderate leisure time energy expenditure of 939±222 kJ per day (224±53 kcal) was associated with the beneficial effect on mortality comparable to that determined in subjects exhibiting more vigorous PA (i.e., those whose energy expenditure equalled to 2,681±213 kJ per day**).** Haskel [26] showed that at least 150 Kcal per day was required to reduce the risk of coronary heart disease and that the CVD risk decreased even more with further elevation of the energy expenditure up to 400 Kcal.

On the other hand, numerous authors showed that even low to moderate PA could be sufficient to help prevent the CVD-associated morbidity and mortality, especially in the elderly. For example, Lemaitre *et al.* [46] reported that in postmenopausal women the risk of myocardial infarction decreased by 50% with modest leisure-time energy expenditures equivalent with walking for 30-45 min. three times a week. In the study of Hakim *et al.* [24] of older men, mortality rate from all causes, from the CVD or stroke, and from cancer was inversely related to the walking distance covered daily. In another study of the middle-aged and older women, the levels of PA inversely correlated with the mortality risk. In that investigation, however, every increase in the activity above the reference level was associated with approximately the same reduction (i.e., by 20-30%) of the risk [80]. Similar results were obtained by Slattery *et al.* [90], who reported that the all-cause- and CVD-associated mortalities among individuals who frequently exercised at light to moderate level were comparable to the mortalities detected in the vigorously exercising subjects. Moreover, Wannamethe and Shaper [104] found that the inverse correlation between PA and the all-causes and the CVD-related mortality rates could be detected only up to the moderate level of PA and that above that level the risk of mortality increased. In turn, as recommended by the Centres for Disease Control and Prevention and the American College of Sports Medicine [72], every adult in the USA should take daily (preferably on every weekday) at least 30 min of the moderate–intensity physical exercise at the recommended intensity of 3-6 METs, i.e., the equivalent of a brisk walking at 3-4 mph. For a human weighing 70 kg such a PA suffices to expend approximately 200 Kcal per day and 1000-1,400 Kcal per week. Therefore, based on the reported epidemiological findings and the recommendations cited above, it can be suggested that older and sedentary people exercise for 30 min daily with the individually-adjusted moderate intensity which could equal to about 3 METs. On the other hand, healthy, physically active young and middle-aged men could expect to have some additional health benefits from expending much more energy during PA so as to reach 2,000-3,000 Kcal or even more per week.

Musculoskeletal fitness

It has been well established that increased level of musculoskeletal fitness may improve the quality of life, especially in the elderly, which in turn can affect the risk of mortality. Only few studies, however, have focused on detection of the possible association between the musculoskeletal fitness and the risk of a premature death. Katzmarzyk and Craig [34] suggested that some components of the muscular fitness, such as the abdominal muscular endurance and the grip strength in males (but not in females) are predictive of the mortality. Metter *et al.* [57] reported that in men younger than 60 years the rate of loss of the muscular strength was more important as predictor of the all-cause mortality than the actual level of strength while in men aged 60 and more years the strength was more important. The inverse association between the musculoskeletal fitness and mortality was demonstrated also by other authors [39,79].

Effect of the cardiorespiratory fitness and physical activity on the coronary artery disease risk factors

Several studies have indicated that low levels of PA and physical fitness are not only independent risk factors for the CVD morbidity and mortality but can also be associated with a number of other CVD risk factors, such as elevated blood pressure (BP), blood glucose level, total and LDL cholesterol, and triacylglycerols levels (TG), as well as decreased HDL cholesterol level, and obesity. For example, Ashton [4] reported that increased physical activity was associated with lower systolic and diastolic blood pressures, lower total cholesterol and total cholesterol to HDL ratio, reduced triacylglycerols, LDL, and blood glucose levels, decreased body mass index, and increased HDL.

Blood pressure: The effect of exercise on blood pressure in patients with hypertension was reviewed by Brown and Hagberg and by Hagberg *et al.* [9,23]. The results of the reviewed studies indicate that the exercise training leads to a decrease in blood pressure in approximately 75% of the individuals whose initial systolic and diastolic BP exceeds 140 and 90 mm Hg, respectively. The average weighted reductions in the systolic and diastolic BP equalled to 10.6 and 8.2 mm Hg, respectively. Interestingly, the average weighted reduction in the systolic BP after training at the intensity less than 70% of VO_2max was even greater than that resulting from training at the intensity exceeding 70% of VO_2max (11.1 mm Hg vs. 7.6 mm Hg). In all the reviewed studies, the training-induced reduction in systolic BP was somewhat more pronounced in the middle-aged subjects presenting with hypertension than in the younger or older subjects. The most favourable effect of the exercise was noted in people with mild hypertension.

Blood lipid and lipoprotein profiles: Adaptation of the blood lipid and lipoprotein profiles to exercise has been recently reviewed by Durstine *et al.* [13]. On the basis of the data reported in the cross-sectional studies these authors suggest that the weekly energy expenditure of 1,200 to 2,200 Kcal is associated with the increases by 2 to 3 mg/dl of the HDL and with the reductions by 8 to 20 mg/dl of the TG levels. Training programmes that entail expenditure of 1,200 to 2,200 Kcal/week per exercise can often lead to elevation of the HDL levels by 2 to 8 mg/dl and to lowering of the TG levels by 5 to 38 mg/dl. However, exercising at that level seldom influences total and the LDL cholesterol levels. In their recent report, Murphy *et al.* [61] showed that walking for 30 minutes at 70-80% of the predicted maximal heart rate resulted in the increased plasma concentrations of HDL and decreased concentrations of total cholesterol and TG.

Diabetes mellitus: Batty *et al.* [5] demonstrated that both the leisure time physical activity and the pace of walking inversely correlated with the all-cause, CHD-, and other cardiovascular diseases-related mortality in both the normoglycaemic and type-2-diabetic or the impaired glucose tolerance subjects. The gradient of the activity-mortality association was steeper, however, in the latter compared to the former subjects. Several long-term follow-up [29,30,51] and cross-sectional [21] studies showed that physical activity may prevent the non insulin-dependent *diabetes mellitus* (NIDDM). In the Pennsylvania Alumni Health Study [29], the occurrence of NIDDM was reduced by 24% for every increment in the leisure-time energy expenditure by 2,000 Kcal per week. The association between the development of NIDDM and physical activity remained even after the adjustment for obesity, hypertension and parental history of diabetes. The protective effect of physical activity was more pronounced in subjects at the highest risk for NIDDM. As indicated by the results of the study of over 21,000 U.S. male physicians, in those who exercised at least once per week the relative (i.e., compared to the less active counterparts) risk factor for developing NIDDM equalled to 0.71 [51]. Frish *et al.* [21] reported that there were fewer cases of NIDDM in the female former college athletes than in their non-athletic counterparts. The inverse correlation between physical activity and the risk of type 2 *diabetes mellitus* was reported in several other studies [17,92,103]. As shown by one recent study carried out in the 69-89-year-old men even trivial types of physical activity such as cycling and gardening may contribute to prevention of the glucose intolerance [103].

Stroke: Although beneficial influence of PA on the risk of a stroke appears to be well documented, the results of several studies suggest that the effect of high physical activity may not be surpass that of the moderate PA. In the Harvard Alumni Health Study [44], the risk of a stroke decreased with the increase in the PA-associated energy expenditure from less than 1,000 to 2,000–2,999 Kcal per week but increased with the further elevation of the expended energy to 3,999 Kcal and more per week. Kiely *et al.* [35] reported on the protective effect in males of the medium- but not low-level metabolic work accomplished during a typical 24-hour period. Interestingly, in the study of these authors, no additional benefit could be detected at the high-level work. In the middle-aged British men exhibiting moderate levels of PA the risk of a stroke was significantly reduced (RR=0.6) compared to the sedentary group of the subjects [104]. In a study carried out on male physicians [42], vigorous exercising at least once a week led to a decrease in the relative risk of a stroke to 0.79. However, no association could be found between the frequency of the exercises (from once to more than five times per week) and the stroke-associated mortality. As indicated by Shinton and Sagar [87], vigorous exercising, even in the relatively young age (15-25 years), can protect against a stroke**.** Lee and Blair [41] reported on the association between the cardiorespiratory fitness and the stroke-induced mortality. In their study carried out on 16,878 men aged 40-87 years, moderate and high levels of the cardiorespiratory fitness were associated with the risks of the stroke-induced mortality of 0.37 and 0.32, respectively, relative to that detected in the low-fitness group of the subjects. As showed by the results of a few studies, the protective effect of physical activity can be modified by sex. In fact, Kiely *et al.* [35] reported that the relation between the level of physical activity and the risk of a stroke was detectable in men but not in women.

Cancer

The effect of PA on the cancer-related death rate is not clear. In the early study of Paffenberger *et al.* [69], mortality from primary cancers from all sites was unrelated to the low energy expenditure associated with the job done by longshoremen. Among the site-specific cancers studied (i.e., of the lung, pancreas, colon, and prostate) only the mortality from lung cancer showed a tendency to correlate with the energy expended during physical activity. In the Multiple Risk Factor Intervention Trial, Leon *et al.* [47] found no relation of PA to the cancer death rate. Similar results were obtained by Polednak [77]. In the majority of epidemiological studies, however, regular PA was associated with a reduced rate of cancer mortality. In fact, the effect of PA on cancer risk differs depending on the site of the cancer. Lee and Paffenberger [45] reported that in 17,607 men aged 30-79 years no significant correlation could be detected between the physical activity and the risk of colon, rectal, prostate, or pancreatic cancers whereas a significant inverse correlation was noted between the level of PA and the risk of death from the lung cancer. There was also a trend toward decreasing the risk of colon cancer with increasing PA but only among quite obese men (Quelet`s index = 26 units). Most of the studies showed that PA is associated with at least moderate reductions in the breast cancer risk [36]. In a nationwide cohort study carried out in Sweden, the relative risk of the prostate cancer morbidity increased with decreasing level of occupational physical activity but no association could be detected between such activity and the prostate cancer mortality [65]. In turn, Hanley *et al.* [25] reported that high level of physical activity reduced the risk of pancreatic cancer in men but PA did not appear to be associated with similar risk in women. The leisure time PA also inversely correlated with the mortality from all cancers while the usual walking pace inversely correlated with the mortality from all cancers, from colorectal cancer and from haematopoietic cancer [11]. The inverse correlation between PA and the risk of colon cancer was reported also by other authors [53,91,98]. Blair *et al.* [6], in the prospective study of healthy men and women found that in the least physically fit group of the subjects the age-adjusted death rate from cancer of all sites combined was more than four times higher than that noted in the two best physically fit groups. In turn, Lee and Blair [40] reported that compared to the low-fitness subjects moderate and high levels of respiratory fitness were associated with lower risk of cancer mortality in both smoking and non-smoking males. The findings of all the above cited and other studies [100] suggest that PA can reduce the risk of colon, breast, and probably lung cancer. Inconsistent results, however, have been obtained on the association between PA and the risk of cancer from other sites.

Sudden cardiac death

High levels of physical fitness and physical activity are generally associated with good health and reduced rate of the premature death. Exercising, however, can also enhance the risk of serious cardiac disorders including sudden cardiac death (SCD). In athletes younger than 30 years the exercise-induced SCD results predominantly from the hypertrophic cardiomyopathy, coronary artery abnormalities, myocarditis, and coronary artery disease whereas in older athletes the coronary artery disease is the main cause of SCD [56]. The major risk factors associated with SCD during downhill skiing are past episodes of myocardial infarction and hypertension (41% vs. 1.5% and 50% vs. 17%, respectively, as compared to the control group of the subjects) [10].

From 1987 to 1996, 51 cases of sudden death in sports were identified in the Republic of Ireland. Of these, in 42 cases the death resulted from the atherosclerotic coronary artery disease [78]. According to Albert *et al.* [1], in the male physicians the relative risk of sudden death during 30 min following a vigorous exertion equalled to 16.9. However, the absolute risk of a sudden death was extremely low (1 death per 1.51 million episodes of exertion). Sudden death associated with physical activity occurred also in school children. As reported by Takada *et al.* [95] who from 1983 to 1994 studied children in Aichi, Japan, 55 out of 76 cases of the sudden death were associated with the engagement in such physical activities as running, swimming, and other competitive sports. The sudden cardiac death during basic military training [75] was also predominantly related to the physical exercising.

In many cases, a thorough medical check-up before the vigorous exercise could have prevented the tragic events. For example, in 27 people who had suddenly died during a sports activity and from 1990 to 1999 were autopsied at the Institute of Forensic Medicine in Paris the following causes of deaths were detected: coronary artery disease (nine cases), hypertrophic cardiomyopathy (five cases), right ventricular dysplasia (three cases), myocarditis (two cases), rupture of aortic aneurysm (four cases), endomyocardial fibrosis (one case), bridging of the left anterior descending coronary artery (two cases), and stroke (two cases). Despite the severity of the lesions, only in four victims the history of a cardiovascular disease was known [19]. On the other hand, many authors reported that some athletes who died during a game had been aware of their cardiovascular problems and had nevertheless continued the training and participated in contests. For example, Noakes [64] who reviewed 36 cases of heart attacks or sudden deaths in the marathon runners found that in 27 cases a coronary artery disease was diagnosed either clinically or at the autopsy. Seventy-one percent of the runners with CVD had premonitory symptoms such as exertional angina, nausea, post-exercise collapse, and ventricular fibrillation. However, regardless of the warning symptoms the majority of these athletes did not withdraw from the training or racing. As estimated by Thompson *et al.* [99], the rate of sudden deaths among joggers on Rhode Island equalled to 13 per 100,000; interestingly, half of the victims had been previously diagnosed with the coronary artery disease and had nevertheless continued the jogging. On the other hand, it is well documented that habitual exercising diminishes the risk of sudden death during a strenuous exertion [1,48,89,109].

Another concern is infections induced by intensive exercising. In fact, it has been repeatedly demonstrated that, in contrast to moderate training, which enhances immune functions, over-training and single exhaustive exercises can increase the susceptibility to bacterial and viral infections [51,62,63]. One of the most serious complications of such infections in an immunocompromised host is myocarditis [20]. In fact, the *Chlamydia pneumoniae*-induced myocarditis was reported to be the cause of sudden cardiac deaths detected among several elite young Swedish orienteers [107,108].

Conclusion

It is well documented that both physical fitness and physical activity are associated with reduction of the mortality from all causes and from cardiovascular diseases. In addition, it has been shown that not only in the young or middle-aged but also in the older people the increase in the level of PA coincides with the reduced morbidity and mortality from a coronary heart disease as well as with the reduced rate of deaths from all causes. Moreover, physical activity and physical fitness appeared to be not only independent protective factors for the CVD-associated mortality but also to have beneficial effects on other CVD risk factors, such as elevated blood pressure and blood glucose level, high total cholesterol and triacylglycerols levels and low HDL cholesterol level. There is also evidence that physical activity protects against stroke and some site-specific cancers. Interestingly, as indicated by the results of several studies, high physical activity does not seem to affect the risk of CVD and stroke more favourably compared to moderate PA. It is not clear, however, which of the two - physical fitness or physical activity - reduces the risk of a premature death to a greater extent. Also, no conclusion has been reached about how intensive physical exercising should be to substantially decrease the mortality rate. Some authors suggested that it is moderate to moderately vigorous activity that suffices to beneficially affect longevity. Moreover, moderate activity is safer, especially for the previously sedentary people. However, in case of the healthy subjects adapted to the high intensity training, the beneficial effect of vigorous exercising should not be neglected.

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