ORIGINAL ARTICLE

Physical Performance in Middle Age and Old Age

Good News for Our Sedentary and Aging Society

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SUMMARY

Background: Physical performance often declines in middle age, but it is unclear to what extent this is due to biological aging. It can be difficult to determine whether such physical changes are truly age-related, as they might alternatively be explained as the negative consequences of a sedentary lifestyle.

Methods: We assessed the endurance of a physically active subgroup of the population by performing an age- and sex-stratified analysis of over 900 000 running times of marathon and half-marathon participants aged 20 to 79. We also analyzed the responses of 13 171 marathon and half-marathon runners to a questionnaire about sports, lifestyle, and health.

Results: No significant age-related decline in performance appears before age 55. Moreover, only a moderate decline is seen thereafter; in fact, 25% of the 65- to 69-year-old runners were faster than 50% of the 20- to 54-year-old runners. Our survey also revealed that more than 25% of the 50- to 69-year-old runners had started their marathon training only in the past 5 years.

Conclusion: Performance losses in middle age are mainly due to a sedentary lifestyle, rather than biological aging. The large contingent of older "newcomers" among marathon runners demonstrates that, even at an advanced age, non-athletes can achieve high levels of performance through regular training.

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In view of the demographic change, ongoing discussions about extending people's working lives, and the widespread problem of insufficient physical exercise and overweight, maintaining health and physical performance have been gaining in importance for some time (1–5). The current aging of the population is obvious from the growing proportion of older people: in 2020, more than 45% of the population in Germany will be older than 60 (6). Age, health, and physical performance have started to attract increasing attention not only from many of those affected and organizations with responsibility for social welfare systems but also from employers: healthy and physically fit older employees are therefore becoming increasingly important, not least because many overweight and unfit youths are barely up to the stresses of everyday working practice (7, 8). An inactive lifestyle and habits that are detrimental to health—such as unhealthy diets, excessive consumption of alcohol, and smoking—can notably affect physical performance even at an early age (9).

Biological aging versus unhealthy lifestyles

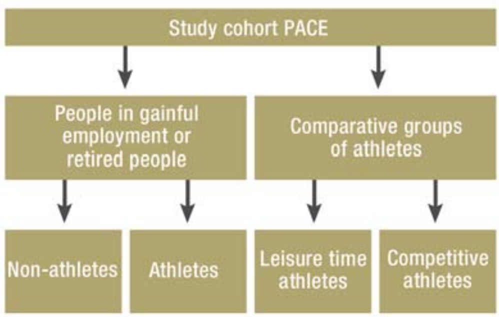
Impairments to physical performance in middle age are often explained with the onset of aging processes. Many sports medical studies have assumed age-related impairments to physical performance from a relatively young age: endurance fitness, for example, has been thought to decrease by 15% per decade after the 30th year of life (10–12). Aging is undoubtedly an inevitable biological process that will sooner or later result in objective performance loss. But comparisons between older performance athletes and their peers who live in sheltered housing for senior citizens have shown that the aging process is individually very different and subject to many factors. However, determining actual age-related changes in physical performance is not a trivial task and is difficult even when using a longitudinal study design.

A general problem lies in distinguishing between age-related influences and those that are primarily a function of changed lifestyle habits or diseases. A reduction in physical performance may well be the result of biological aging processes. However, physical performance may also decline over the years because

BOX

PACE (Performance, Age, Competition, Exercise) study

The investigators of the PACE study, which has been running since 2005, are collecting data from people aged 18 to 100 about their everyday lifestyle habits, work stresses, and physical performance and health characteristics. The cross-sectional study looks at the staff in private and public companies (people in gainful employment) and people



Graphical representation of the PACE cohorts

in retirement as well as several athletic comparative cohorts (for example, long-distance runners, walkers, cyclists, swimmers, gymnasts, and those doing weight training) and non-athletes. The aim is to assess the influence of lifestyle habits and physical activity or inactivity on health and the ability to work/perform and to support the implementation of health promotion initiatives (individual, occupational, school-related).

people do not have time for regular exercise owing to work-related or family-related obligations (such as career progression or raising children). In such cases, a performance loss seen in a longitudinal sample is not solely responsible for the aging process (13–16).

Marathon running as a study model for physical performance

In view of the necessary distinction between age-related and lifestyle-related effects, marathon running is an excellent model for studying the physiology of performance. In contrast to shorter running distances (for example, 5000 meters or 10 000 meters), which untrained individuals can master, a marathon competition or a half-marathon can usually be completed successfully only if the individual has trained/exercised for the event for a lengthy period of time and has a clear focus on sports activities in everyday life (17). It is therefore not surprising that widespread, detrimental, health relevant characteristics—such as obesity, smoking, and lack of exercise—are much rarer in this cohort.

Consequently, the age-associated performance losses observed in marathon running are caused by biological aging processes rather than unfavorable lifestyles. Marathon competitions, with thousands of participants from all age groups, have a further great methodological advantage: the lists of results provide epidemiological data such as age, sex, and electronically measured running times for participants. Even if it is not our intention to promote participation in marathons or half-marathons, these data are excellent for model studies for the purposes of preventive medicine (13).

The PACE study—performance analyses and surveys of athletes

In the context of the PACE (Performance, Age, Competition, Exercise) study (*Box*) running times for 552 528 marathons and 374 425 half-marathons with participating long-distance runners aged 20–79 were analyzed. Further, more than 13 000 long-distance runners were surveyed by using a scaled questionnaire that posed questions about:

- The training schedule
- Motivation for doing physical exercise
- Health
- Sports medical care
- Everyday lifestyle habits
- Work/employment
- Biometric data such as height and weight.

The survey was administered online (www.dshs-koeln.de/pace) and by means of face-to-face interviews at marathon and half-marathon events.

In this article, we investigate age-associated changes to running times and some preventive medical aspects—such as training, tobacco consumption, prevalence of overweight/obesity—using the example of a population group that is self motivated to practice effective, health relevant exercise and behavioral measures.

Method

Running times and surveys of the long-distance runners were approved by the ethics committee at the German Sport University in Cologne (Deutsche Sporthochschule Köln) and cleared by the data protection officer for the state of North-Rhine Westphalia.

Analysis of running times

As described earlier (18, 19), we analyzed 135 marathon competitions and 110 half-marathons from the years 2002–2009. The lists of participants from the result scores were pseudonymized and stored as a code in a database with the associated variables age, sex, and running time. By using the variables code, age, and sex, participants who ran in more than one competition were identified as repeat runners. For such repeat participants, only one running time was selected in a randomized manner and included in the analysis. Owing to the extensive data collection with more than 900 000 running times, the following age groups of 20- to 79-year old marathon and half-marathon participants were formed (*Tables 1 and 2*):

- Group 25=20–29 years
- Group 32.5=30–34 years
- Group 37.5=35–39 years
- Group 42.5=40–44 years
- Group 47.5=45–49 years
- Group 52.5=50–54 years
- Group 57.5=55–59 years
- Group 62.5=60–64 years
- Group 67.5=65–69 years
- Group 72.5=70–74 years
- Group 77.5=75–79 years.

Survey of participants

The internet survey—including the acquisition of the sample and the validation by means of complementary face-to-face surveys, among others, about training, motivation, health, and sports medical examinations—was independent of the running time and was described in detail and methodologically evaluated in *Deutsches Ärzteblatt International* (20). For our article, we analyzed data from 13 171 athletes aged 20–69 years (*Tables 3a and 3b*). We included only runners in the evaluation who had previously completed a marathon or half-marathon or who were in preparation for such a competition.

In addition to biometric baseline data such as age, sex, and height/weight we evaluated participants' self reported data on work/employment, sports/exercise, and leisure time, as well as health. For the "work" topic, we included questions regarding their current job position and classified the information by economic sector, on the basis if a three-sector model including the primary sector (conservation/agriculture), secondary sector (manufacturing/processing), and tertiary sector (services). Regarding sports activities, participants were asked how they classify themselves in terms of sports (leisure time athlete, competitive athlete), how they structure their running training (for example, frequency or distances covered), and whether they were active in any other type of sports currently or before they took up their running training. Further, we analyzed health relevant aspects, such as tobacco consumption and prevalence of overweight/obesity. In a subsample of the cohort with more than 2000 subjects, we additionally asked for posture adopted at work and the frequency of physical exercise per week.

On the basis of individual age, the surveyed participants were categorized as follows:

- Group 25 = 20–29 years
- Group 35 = 30–39 years
- Group 45 = 40–49 years
- Group 55 = 50–59 years
- Group 65 = 60–69 years.

TABLE 1

Absolute and relative number of marathon running times data from 135 marathon competitions in Germany in 2002 to 2009 (n = 376 313)

Age group (years)	Study participants running time analysis			
	Men		Women	
	(n)	(%)	(n)	(%)
20–29	36 611	12.0	10 934	15.5
30–34	38 269	12.5	10 512	14.9
35–39	61 597	20.1	14 128	20.1
40–44	66 674	21.8	15 529	22.1
45–49	46 800	15.3	10 406	14.8
50–54	31 261	10.2	5805	8.2
55–59	13 307	4.4	1922	2.7
60–64	7595	2.5	867	1.2
65–69	2842	0.9	260	0.4
70–74	827	0.3	58	0.1
75–79	105	0.0	4	0.0
Total	305 888	100.0	70 425	100.0

The percentages have been rounded to one decimal place

TABLE 2

Absolute and relative number of half marathon running times (data from 110 marathon competitions in Germany in 2002 to 2009) (n = 237 028)

Age group (years)	Study participants running time analysis			
	Men		Women	
	(n)	(%)	(n)	(%)
20–29	26 081	15.5	14 183	20.6
30–34	22 181	13.2	10 664	15.5
35–39	32 411	19.3	13 641	19.8
40–44	35 386	21.0	14 192	20.6
45–49	23 307	13.9	8779	12.7
50–54	16 090	9.6	4906	7.2
55–59	6603	3.9	1573	2.3
60–64	3765	2.2	651	0.9
65–69	1673	1.0	204	0.3
70–74	573	0.3	59	0.1
75–79	93	0.1	13	0.0
Total	168 163	100.0	68 865	100.0

The percentages have been rounded to one decimal place

TABLE 3a

Absolute and relative number and anthropometric data of male long-distance runners (n = 9913)

Age group (years)	Male study participants				
	Number		Height	Weight	Body mass index
	(n)	(%)	(cm)	(kg)	(kg/m²)
20–29	1304	13.1	181.7 ± 6.7	76.1 ± 9.7	23.0 ± 2.4
30–39	2607	26.3	181.2 ± 6.9	78.5 ± 10.0	23.9 ± 2.5
40–49	3971	40.1	180.4 ± 6.3	78.1 ± 9.1	24.0 ± 2.3
50–59	1629	16.4	178.9 ± 6.5	77.6 ± 9.3	24.2 ± 2.3
60–69	402	4.1	176.4 ± 6.2	74.5 ± 8.5	23.9 ± 2.2
Total	9 913	100.0	180.4 ± 6.7	77.7 ± 9.5	23.9 ± 2.4

The percentages have been rounded to one decimal place

TABLE 3b

Absolute and relative number and anthropometric data of female long-distance runners (n = 3258)

Age group (years)	Female study participants				
	Number		Height	Weight	Body mass index
	(n)	(%)	(cm)	(kg)	(kg/m²)
20–29	678	20.8	168.7 ± 6.7	61.8 ± 9.0	21.7 ± 2.8
30–39	911	28.0	169.4 ± 6.3	62.4 ± 8.3	21.7 ± 2.3
40–49	1198	36.8	168.1 ± 6.4	62.2 ± 8.3	22.0 ± 2.4
50–59	402	12.3	166.1 ± 64	60.9 ± 8.4	22.0 ± 2.5
60–69	69	2.1	166.0 ± 6.6	59.9 ± 6.2	21.8 ± 1.9
Total	3258	100.0	168.3 ± 6.5	62.0 ± 8.5	21.8 ± 2.5

The percentages have been rounded to one decimal place

Risk factors

The prevalence rates of selected health risk factors for cardiovascular diseases—such as smoking, obesity, and lack of exercise—were calculated by using WHO criteria (9). One or more risk factors are present if the following values are exceeded or one of the listed characteristics applies:

- Obesity (body mass index [BMI] $\geq$ 30 kg^2/m)
- Smoking
- Lack of exercise (subjective assessment of frequency of sports activities in the categories "never" or "rarely and irregularly").

Data presentation and statistical analyses

SPSS 17.0 and Statistica 7.1 were used for the statistical analyses. As the descriptive measures for position, scattering, and distribution we determined mean values, standard deviations, and percentile distributions (5th, 25th, 50th, 75th, and 95th percentile). Differences in the means were checked by using degrees of freedom using *t* tests (test statistic T) and analysis of variance (test statistic F). Multiple comparisons (post-hoc test, test statistic MQ) were done by using the Newman-Keuls test, dichotomous or ordinal parameters were statistically evaluated by using the Chi Square test (test statistic Chi^2) and/or binary logistic regression. For the binary logistic regression we reported odds ratios (OR) and 95% confidence intervals (CI). The significance level for differences between groups was p<0.01.

Results

The running times of 376 313 marathon runners and 237 028 half-marathon runners were analyzed by age and sex (*Tables 1, 2*). *Figure 1* shows the marathon running times for 20–79 year old athletes. Significant age-related performance losses occurred in women as well as in men only in the groups of those older than 54 years (MQ = 1311.0; p<0.001). For half-marathons, performance losses were also noted only for the groups of participants older than 54 (MQ = 239.29; p<0.001). For both distances, the performance losses are small. A substantial proportion of the older athletes are actually faster than most of the younger marathon and half-marathon runners. *Figure 1* shows that half of the runners aged 20–54 reach the finishing line only after the best 25% of the 65–69 year old runners.

The interviews with the athletes also showed that older endurance athletes do not undergo more running training. For marathon training (age: $F_{(4.7725)} = 1.09$; $p \geq 0.20$/sex: $F_{(1.7725)} = 2.89$; $p \geq 0.05$) as for half-marathon training (age: $F_{(4.2897)} = 1.77$; $P \geq 0.10$/sex: $F_{(1.2897)} = 1.08$; $p \geq 0.20$), no significant differences exist between age groups or between the sexes. Some 70% of athletes trained 3–4 times a week (*Figure 2*). For a mean duration of training of 61.5 ± 18.5 minutes or 70.3 ± 24.4 minutes (half-marathon runners versus marathon runners; $t_{(961.45)} = 6.90$; p<0.001) per unit of training, the mean distance covered was 10.8 ± 3.3 km or 12.9 ± 3.5 km (half-marathon runners versus marathon runners; $t_{(5551.20)}$=27.37; p<0.001).

A notable association with age existed for the question: "Since when have you conducted your regular running training?" 20–29 year olds reported a mean of 3.9±3.7 years of training, whereas the 60–69 year olds reported 15.5 ± 12.7 years ($F_{(4.12916)}$=430.78); p<0.001). Further data analysis shows, however, that a substantial proportion of the older athletes only took up training a few years previously (*Figure 3*). One third of the 50–59 year olds and one quarter of 60–69 year olds reported having taken up running training in the preceding 5 years.

35.2% of runners did not pursue any regular sports activities before taking up running. *Figure 4* shows that this proportion increases with increasing age. Some 42% of those older than 50 were non-active before taking up running. Relative to the 20–29 year olds, in the older groups notably fewer persons reported not pursuing sports previously (OR 3.01; 95% CI 2.44 to 3.72). 79.6% of runners classify themselves as leisure time athletes or weekend athletes.

In addition to the data on exercise, two further indicators were analyzed that are important for the purposes of preventive medicine: the classification of body weight using WHO criteria (BMI) and the proportion of smokers. The proportion of smokers in endurance athletes was 6.9%. 23.3% of those surveyed categorized themselves as former smokers; 70.2% had never smoked regularly. No differences existed between the sexes ($Chi^2_{(1,n=12921)}$=3.29; p ≥ 0.01); the proportion of smokers fell after the 50th year of life ($Chi^2_{(4,n=12921)}$=40.05; p<0.001).

Female runners (21.8 ± 2.4) had notably lower BMI values than male runners (23.9 ± 2.5) ($t_{(13168)}$=40.86; p<0.001). By age, BMI increases only in men (*Table 3*), and only slightly (MQ = 5.85; p<0.001). The BMI values of the surveyed endurance athletes according to the WHO categories are as follows:

- 1.4% with a BMI<18.5
- 75.7% with a BMI ≥ 18.5 und <25
- 21.3% with a BMI ≥ 25 und <30
- 1.6% with a BMI ≥ 30.

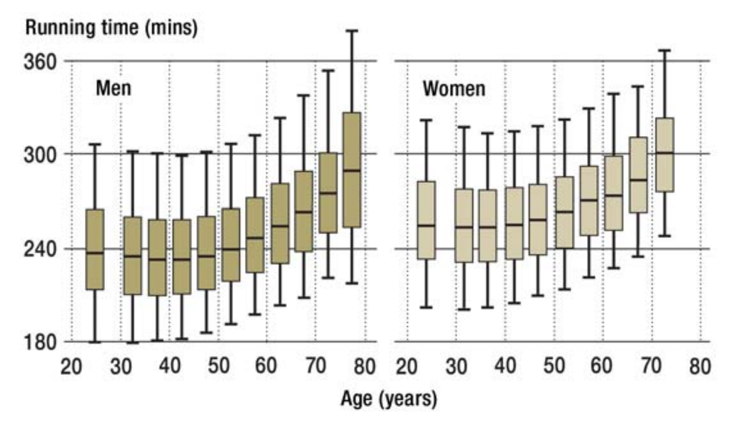
91.8% of runners had no cardiovascular risk factors (*Figure 5*). No differences exist between the sexes. ($Chi^2_{(2,n=13171)}$ = 0.38; P ≥ 0.20).

The data on gainful employment show that the majority of runners work in the service sector and that most of their jobs are sedentary (*Figure 6*). Only in individual cases did runners report working in jobs that required physical stamina, such as the trades.

Discussion

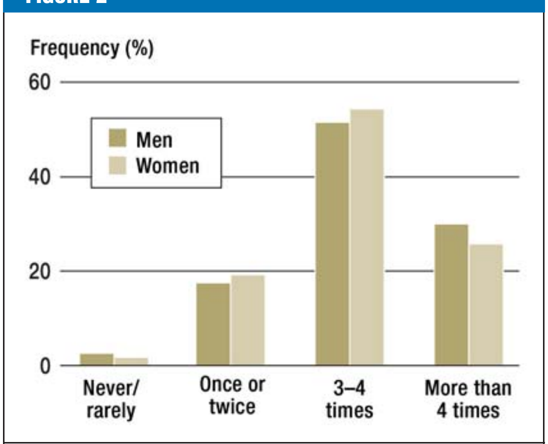
This study of a physically active subpopulation has yielded remarkable findings with regard to age-associated changes. The running time analyses for 20- to 79-year-old long-distance runners confirm that middle age alone is not a cause of performance loss and that by means of regular training, older people can achieve impressive performance results. Significant deteriorations in marathon or half-marathon competitions occur only in the age groups older than 54. A substantial proportion,

FIGURE 1



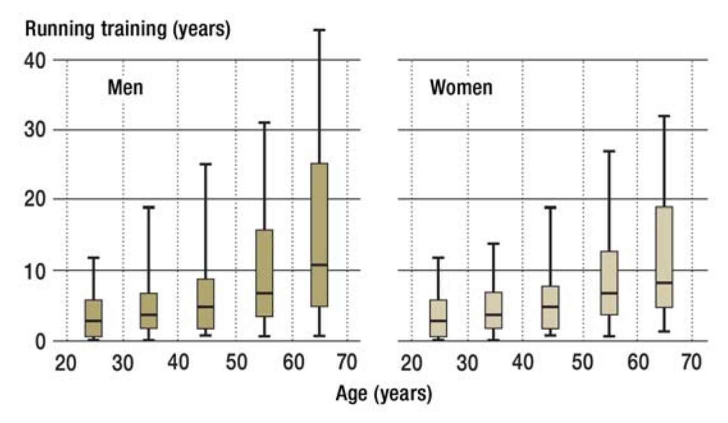
Running times of male (n = 305 888) and female (n = 70 425) participants in 135 marathon competitions. The figure shows the 5th, 25th, 50th, 70th, and 95th percentile of those who finished the race ("finishers")

FIGURE 2



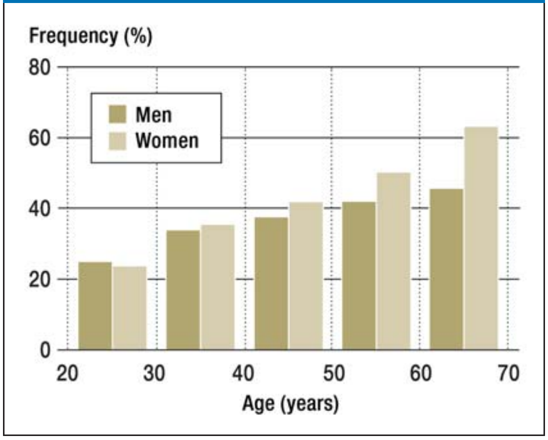
Distribution (%) of weekly exercise sessions of the runners (men: n = 1365, women: n = 746)

FIGURE 3



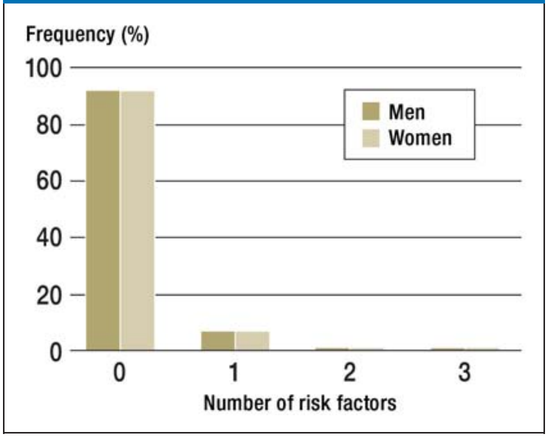
Experience in running training among men (n = 9726) and women (n = 3195). The figure shows the 5th, 25th, 50th, 70th, and 95th percentile

FIGURE 4



Proportion (%) of endurance athletes who did not do any regular sports before taking up running (men: n = 9565, women: n = 3164)

FIGURE 5



Frequency (%) of cardiovascular risk factors (smoking, lack of exercise, obesity) in long-distance runners (men: n = 9913, women: n = 3258)

25%, of older athletes is faster than half of the younger ones. The measured running times of older athletes were collected from a comparatively small number of older participants (*Tables 1 and 2*), so that the question arises of whether the age groups are comparable. Even though the permanence of performance described in this article will not apply to everyone when comparing age groups, from an epidemiological perspective, the minute changes in the range of running performances (5^{th} to 95^{th} percentile) in the different age groups are contradictory to a fundamental limitation.

The survey also showed that older people do not train more in order to achieve their performance level than younger people. With regard to relevant parameters such as distance covered, duration of training, and frequency of training, those aged 20–69 did not differ statistically from one another. The training of most long-distance runners was not substantially above the level of activity recommended by WHO for preventive medical purposes (physical exercise 5 times a week for at least 30 minutes) (21). Some 70% of athletes trained an average of no more than 3–4 times a week for about 1 hour.

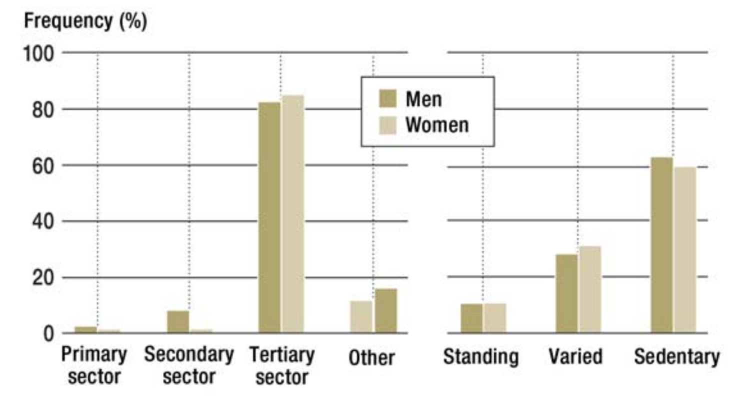
With regard to older athletes, the surveys showed a surprising result that is encouraging for our aging and increasingly inactive society: more than one quarter of 50–69 year olds took up running only within the preceding 5 years (*Figure 3*). This means a substantial number of sports novices who successfully completed a marathon within merely a few years. Physical performance and ability to train are also determined genetically (22, 23). A recently published longitudinal study including men older than 50 showed impressively the great effectiveness of regular sports activities at an older age (24): the life expectancy of active seniors was 3.8 years longer than that of their non-active peers. But even non-trained people who had taken up sports only after the age of 50 were able to halve their mortality risk compared with their non-active peers. Such effects are also likely to have benefited numerous participants in our study: the majority of subjects works in mostly sedentary jobs that are physically undemanding, which might have numerous negative effects on their health and are being discussed as an independent mortality factor (2). More than one third of subjects in the study did not pursue any sports activity before taking up running. However, this group of people should seek advice from a qualified sports physician and have a health check-up (20).

Limitations of the study

When critically reviewing the study, several questions arise with regard to its methodological limitations. In addition to the known limitations of a cross-sectional study design (for example, cohort effects), it needs to be made clear that the study cohorts ("running time analysis" and "survey") are not completely identical. The comparison between the study populations shows however, that both groups are consistent in terms of age and sex distributions and the participation rates in marathon and half-marathon competitions (*Tables 1–3*). Further, the extent to which the results of a non-representative subgroup of the population can be translated to the general population requires discussion. Certain typical criteria, such as data on education, gainful employment, or income are available only for some of the study subjects.

By contrast, many of the sports novices were from groups targeted by health initiatives that focus, among others, on people who are not physically active and have sedentary jobs that pose no physical challenge (*Figure 6*). Training-induced adaptations are not primarily dependent on criteria of representativeness. Rather, trainability is determined by fundamental physiological adaptive processes, behavioral traits (training), and genetic factors. As far as the comments about trainability in this study go, we wish to critically remark that no longitudinal data were available. This means that data on individual performance development are lacking. However, the sheer fact that even non-trained older sports novices were able to run a marathon after only a few years of regular training is a clear proof of their trainability.

FIGURE 6



Distributions (%) of job positions held by economic sector (left) (men: n = 8718, women: n = 2885) and different bodily posture adopted at work (right) (men: n = 1339, women: n = 727). Explanation: primary sector = conservation/agriculture, secondary sector = production and manufacturing, tertiary sector = services

Conclusion

In spite of methodological limitations, the model character of the study of long-distance runners indicates that the documented results are relevant, especially for the whole area of endurance training. Further, the risk factors, health impairments, and observed performance losses that often occur in the population in the middle years of life are not caused by aging per se but primarily by unhealthy life habits and lack of exercise. Our analyses show that a subpopulation of the general population is successful and self motivated in practicing health-relevant exercise and behavioral measures and that numerous former non-athletes have successfully entered into such routines.

In view of health promotion and prevention campaigns it remains unsatisfactory, however, that not much is known about the actual target groups—non-athletes with health risk factors and impaired performance (25). In the context of the PACE study, non-athletes are currently being interviewed in order to obtain quantifiable data on the causes of athletic abstinence and to describe in greater detail potential attractors for physical activity. The aim is to shape prevention measures in a way that is appropriate to the target audience and to implement these sustainably.

Conflict of interest statement
The authors declare that no conflict of interest exists according to the guidelines of the International Committee of Medical Journal Editors.

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