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Physical activity types, variety, and mortality: results from two prospective cohort studies

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ABSTRACT

OBJECTIVE To examine the associations of long term engagement in individual physical activities and physical activity variety with the risk of death.

DESIGN Prospective cohort studies.

SETTING Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020).

PARTICIPANTS 70 725 women and 40 742 men who were free of diabetes, cardiovascular disease, cancer, respiratory disease, or neurological disease and had complete physical activity information at baseline (leisure time physical activity was biennially updated using validated questionnaires during follow-up; the variety of physical activity was measured as the total number of individual physical activities in which participants consistently engaged).

MAIN OUTCOME MEASURES All cause and cause specific mortality.

RESULTS During 2 431 318 person years of follow-up, 38 847 deaths were recorded, with 9901 from cardiovascular disease, 10 719 from cancer, and 3159 from respiratory disease. Total physical activity and most individual physical activities, except for swimming, were associated with lower mortality with non-linear dose-response relations. The pooled multivariable adjusted hazard ratios for all cause mortality in the highest categories of physical activity levels, compared with the lowest, were 0.83 (95% confidence interval 0.80 to 0.85) for walking, 0.89 (0.85 to 0.94) for jogging, 0.87 (0.80 to 0.93) for running, 0.96 (0.93 to 0.99) for bicycling, 1.01 (0.97 to 1.05) for swimming, 0.85 (0.80 to 0.89) for tennis or squash, 0.90 (0.87 to 0.93) for climbing stairs, 0.86 (0.84 to 0.89) for rowing or callisthenics, and 0.87 (0.82 to 0.91) for weight training or resistance exercises. Higher physical activity variety was associated with lower mortality. After adjustment for total physical activity levels, participants in the group with the highest physical activity variety score (group 5), compared with those in the lowest group (group 1), had a 19% lower all cause mortality and 13-41% lower mortality from cardiovascular disease, cancer, respiratory disease, and other causes (all P for trend <0.001).

CONCLUSIONS Habitual engagement in most types of physical activity was associated with lower mortality. The variety of physical activity was inversely associated with mortality, independent of total physical activity levels. Overall, these data support the notion that long term engagement in multiple types of physical activity may help extend the lifespan.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Total physical activity levels have consistently been associated with lower mortality in a non-linear dose-response relation, but evidence for individual physical activities is limited

⇒ Previous studies have suggested that different types of physical activity may have distinct physiological effects

⇒ Whether long term engagement in multiple physical activities has additional benefits beyond total physical activity levels is unclear

WHAT THIS STUDY ADDS

⇒ Most individual physical activities were associated with lower mortality in a non-linear manner

⇒ The variety of physical activity was associated with lower mortality, independent of total physical activity levels

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ The findings support the notion that promoting engagement in a diverse range of physical activity types, alongside increasing total physical activity levels, may help reduce the risk of premature death

Introduction

Engaging in leisure time physical activity is one of the cornerstones of the numerous lifestyle recommendations for improving human health.[1 2] Long term engagement in physical activity is unequivocally associated with a reduced risk of multiple chronic diseases, improved mental health, and a better chance of achieving longevity and healthy ageing.[3–5] Despite abundant literature on the health benefits of total physical activity, data on individual physical activities are still sparse.[6]

Emerging evidence has implied that different types of physical activity may exert distinct physiological effects on body composition, cardiorespiratory fitness, metabolic profiles, and bone strength.[6–8] For example, a recent short term lifestyle intervention showed that aerobic exercise improved cardiorespiratory fitness by increasing peak oxygen consumption but had minimal effect on muscular strength.[7] Conversely, resistance training enhanced muscular strength without substantially changing peak oxygen consumption, whereas combining both modalities gave improvements in both domains. Thus individuals might benefit more from engaging in multiple physical activities with complementary health effects than from focusing on only one type of activity.[7 8] The long term health benefits of consistently engaging in different physical activities on survival have not been investigated extensively, and data specifically focused on the influence of physical activity variety are lacking. Although a limited number of studies have evaluated multiple physical activities simultaneously in relation to mortality,[9–15] most have not directly looked at whether the variety of physical activities had additional advantages beyond the total amount of physical activity.

Based on data from two large cohort studies with repeated physical activity assessments over 30 years of follow-up, our aim was to investigate the associations of several commonly practised physical activities and physical activity variety with all cause and cause specific mortality. We also examined the joint association of total physical activity levels and physical activity variety with mortality.

Materials and methods

Study population

The Nurses' Health Study started in 1976 when 121 700 female registered nurses aged 30-55 years were enrolled. The Health Professionals Follow-Up Study began in 1986 when 51 529 male health professionals aged 40-75 years were recruited. In both cohorts, participants reported their personal characteristics, medical history, and lifestyle information on enrolment, and provided biennial updates by completing follow-up questionnaires. The cumulative response rate in both cohorts was >90%.

Our study included participants with complete physical activity information in 1986. To reduce the potential reverse causation influence, we applied a four year lag time between assessing physical activity and the time at risk of death. We also excluded participants with a diagnosis of diabetes, cardiovascular disease, cancer, respiratory disease, or neurological disease at baseline to alleviate potentially strong confounding by existing diseases. Hence we included 111 467 participants in the analysis of physical activity levels; 70 725 from the Nurses' Health Study and 40 742 from the Health Professionals Follow-Up Study. Analysis of physical activity variety was limited to 111 373 participants; 70 725 women and 40 648 men who reported engaging in any physical activity.

Assessment of physical activity

Detailed information on leisure time physical activity was first collected in 1986 and updated biennially. Up to 15 repeated assessments were available for each participant (median 13, interquartile range 9-14), based on the same question: "During the past year, what was your average time per week spent at each activity?". In both cohorts, data on walking, jogging (<10 min/mile (1.6 km)), running (≥10 min/mile), bicycling (including stationary machine), lap swimming, rowing or callisthenics, and tennis, squash, or racquetball were recorded from 1986. Information about weight training or resistance exercises was added to the Nurses' Health Study in 2000 and to the Health Professionals Follow-Up Study in 1990. Lower intensity exercises (eg, yoga, stretching, and toning) were added to the Nurses' Health Study in 1992 and to the Health Professionals Follow-Up Study in 2010. Also, other vigorous activities (eg, lawn mowing) were included in the Nurses' Health Study from 1992 onwards. In the Health Professionals Follow-Up Study, moderate outdoor work (eg, yardwork and gardening) was asked from the beginning of 2004, and heavy outdoor work (eg, digging and chopping) from 1988. Participants were also asked: "How many flights of stairs (not individual steps) do you climb daily?". The average weekly time spent on climbing flights of stairs was estimated based on their responses to this question, assuming each flight takes eight seconds to ascend.

Based on a compendium of physical activities,[16] each activity was assigned a metabolic equivalent task (MET) score, which represents the metabolic rate for that specific activity divided by the resting metabolic rate. The MET hours/week for each physical activity was derived by multiplying the average time spent on the activity (in hours/week) by its MET score. Total physical activity was defined as the sum of specific MET hours/week across all physical activities in each questionnaire cycle. The reproducibility and validity of the self-administered physical activity questionnaires used in both cohorts have been reported previously.[17–20] For example, the estimated correlations between the physical activity questionnaire and true level of total activity were 0.54 in women and 0.60 in men; for moderate-to-vigorous activity, the correlations were 0.60 and 0.69, respectively.

For individual physical activities, our pooled analyses included nine physical activities recorded in both cohorts: walking, jogging, running, bicycling, swimming, rowing or callisthenics, tennis, squash, or racquetball, climbing flights of stairs, and weight training or resistance exercises. Given the limited follow-up time for the lower intensity exercises in the Health Professionals Follow-Up Study, we examined its association with mortality only in the Nurses' Health Study. Other cohort specific activities were analysed in the Nurses' Health Study (other vigorous activities) or Health Professionals Follow-Up Study (moderate outdoor work and heavy outdoor work), respectively.

To measure the variety of physical activities, we constructed a score by summing the number of individual physical activities in which participants

Table 1 | Age standardised characteristics of person years by total physical activity level (divided into five equal groups) during follow-up*

	Total physical activity level				
	Group 1 (lowest)	Group 2	Group 3	Group 4	Group 5 (highest)
No of person years	483 008	485 993	486 688	487 862	487 767
Mean (SD) total physical activity† (MET hours/week)	3.6 (2.9)	9.4 (5.0)	16.1 (7.1)	25.8 (9.6)	51.6 (23.9)
Mean (SD) age (years)†‡	63.6 (10.6)	63.5 (10.5)	63.5 (10.5)	63.5 (10.5)	63.6 (10.5)
Men	33.9	34.0	34.0	34.0	34.0
White ethnic group	96.5	97.0	97.3	97.3	97.2
Mean (SD) baseline body mass index	26.3 (4.9)	25.5 (4.2)	25.1 (3.9)	24.7 (3.7)	24.2 (3.5)
Family history of myocardial infarction	20.9	20.4	20.2	20.7	20.5
Family history of cancer	55.6	55.8	55.9	56.4	55.8
Baseline hypertension	23.8	21.1	19.8	18.6	17.2
Baseline hypercholesterolaemia	11.5	10.8	10.7	10.5	10.0
Current smoker†	12.3	9.8	8.5	7.8	7.4
Mean (SD) alcohol intake (g/day)†	7.1 (11.7)	7.3 (11.0)	7.7 (10.9)	8.1 (10.9)	8.7 (11.1)
Mean (SD) total energy intake (kcal/day)†	1757 (495)	1788 (486)	1807 (487)	1831 (494)	1875 (523)
Mean (SD) modified alternative healthy eating index†§	44.0 (9.1)	45.9 (9.2)	47.4 (9.2)	48.7 (9.4)	50.5 (9.7)
Mean (SD) social integration index†	6.0 (3.1)	6.4 (3.1)	6.5 (3.1)	6.6 (3.1)	6.7 (3.1)
Mean (SD) physical activity variety score†¶	0.9 (0.6)	1.7 (0.7)	2.1 (0.8)	2.5 (0.9)	3.1 (1.1)

1 kcal=4.18 kJ=0.00418 MJ.

Values are percentages unless indicated otherwise.

*In 111 467 participants (2 431 318 person years). Categorisations were conducted based on the distributions within each cohort and then pooled together. Median values for total physical activity level (metabolic equivalent task (MET) hours/week) in each group were 2.3, 6.8, 12.1, 19.9, and 37.2 in the Nurses' Health Study and 5.5, 14.8, 24.7, 37.5, and 62.5 in Health Professionals Follow-Up Study, for groups 1-5, respectively (online supplemental table 5).

†Data were updated during follow-up.

‡All variables were standardised to the age distribution of the study population, except for age.

§Scores for modified alternative healthy eating index (alcohol component excluded) range from 0 to 100; higher scores indicate a healthier diet.

¶In 111 373 participants reporting any physical activity (2 419 876 person years). The physical activity variety score was calculated as the sum of individual physical activities consistently performed (one point for each physical activity meeting the predefined threshold; otherwise 0). The cumulative average during follow-up assessed long term physical activity variety.

MET, metabolic equivalent of task; SD, standard deviation.

consistently engaged, counting each physical activity as one if it met the predefined threshold and zero otherwise. The thresholds were set at five flights/day for stair climbing and 20 min/week for other activities, and were converted into MET hours/week by multiplying the reported duration by the specific MET value assigned to each activity (online supplemental table 1). The maximum number of individual physical activities was 11 in the Nurses' Health Study and 13 in the Health Professionals Follow-Up Study. This score was derived from the updated measure of physical activity levels for each follow-up cycle and then cumulatively averaged to represent the long term physical activity variety.

Covariates

Information on age, ethnic group, weight, family history of diseases, medical history, smoking status, menopausal status, and postmenopausal hormone use was assessed and updated biennially. Body mass index was calculated, and diet and alcohol intake were assessed with validated semi-quantitative food frequency questionnaires every two or four years. The modified alternate healthy eating index, excluding the alcohol component, was calculated to reflect overall quality of the diet.[21] To reduce potential reverse causality, we stopped updating dietary information when participants developed chronic diseases (including diabetes, cardiovascular disease, cancer, respiratory disease, and neurological disease) during follow-up. Cumulative averages of dietary intake were used to represent habitual intake. Social integration was measured with a seven item index, covering marital status, social network size, contact frequency, religious participation, and involvement in other social groups.[22 23]

Ascertainment of death

Deaths were identified by searches of the National Death Index or reports from participants' next-of-kin or postal service, and >97% of deaths were determined for both cohorts.[24 25] The cause of death was determined by review of medical records and death certificates by the study physicians. We used the ICD-8 (international classification of diseases, eighth revision) codes in the Nurses' Health Study and ICD-9 (international classification of diseases, ninth revision) codes in the Health Professionals Follow-Up Study, which were widely used at the start of the cohorts to distinguish deaths from cardiovascular disease (ICD-8: 390-458, 795; ICD-9: 390-459, 798), cancer (ICD-8: 140-207; ICD-9: 140-208), respiratory disease (ICD-8 and ICD-9: 460-519), and other causes.

Statistical analysis

Person years was calculated from baseline to the date of death or end of follow-up (June 2018 for the Nurses' Health Study and January 2020 for the Health Professionals Follow-Up Study), whichever occurred first. During follow-up, missing data for individual physical activities and covariates were replaced with valid values from the preceding questionnaire for one cycle. Person years were not accrued during cycles with missing physical activity data; participants contributed person years only in cycles where physical activity data were available.

For covariates, the missing indicator method was used to deal with any remaining missing data. The proportions of missing observations were 1.6% for alcohol consumption, 1.6% for total energy intake, 1.7% for the modified alternative healthy eating index, 2.0% for baseline body mass index, 3.0% for smoking status, 5.1% for postmenopausal hormone use (among women), and 12.0% for the social integration index. In previous analyses conducted within our cohorts, the missing indicator method gave results that were largely consistent with those obtained from multiple imputation.[26] To enhance the statistical power of the study, we pooled individual level data from both cohorts in the primary analyses, harmonising covariates to ensure consistent definitions and measurements across the two studies. Cohort specific associations were also examined as secondary analyses.

To minimise reverse causation bias, where individuals might reduce physical activity because of illness, we stopped updating physical activity if participants reported a diagnosis of diabetes, cardiovascular disease, cancer, respiratory disease, or neurological disease, and carried forward the last physical activity value before diagnosis for subsequent follow-up cycles. Repeated measures of physical activity levels were cumulatively averaged to represent long term engagement and to reduce within person random measurement error. The relation between the amount and variety of physical activity was examined with Spearman's correlation coefficients, adjusting for age. We categorised total and individual physical activity levels and physical activity variety scores according to their distributions within each follow-up cycle and cohort: total physical activity levels and physical activity variety scores were divided into five equal groups; levels of walking and climbing flights of stairs were divided into four equal groups; for other individual physical activities, because of the skewed distribution towards zero, those who did not participate in the specific activity were categorised as the reference group and the remaining participants were categorised into three equal groups.

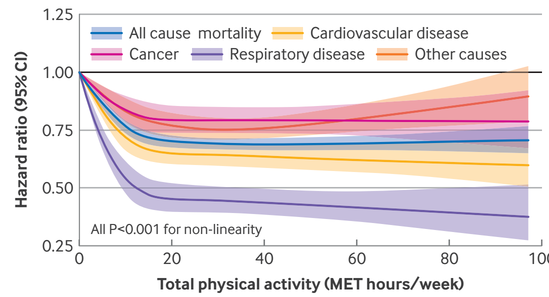

Figure 1 | Dose-response relations between total physical activity and mortality. Pooled results from Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020). Data were truncated at the 99th centile value. Models were stratified by age (months), calendar time, and cohort, and were adjusted for ethnic group (white or non-white participants), family history of myocardial infarction or cancer (yes or no), body mass index at baseline (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0), postmenopausal hormone use (women only; premenopausal, never, former, or current use), smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day), alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day), total energy intake (five equal groups), modified alternate healthy eating index score (five equal groups), social integration index (four equal groups), and baseline hypertension or hypercholesterolaemia (yes or no). In the models for respiratory disease mortality, postmenopausal hormone use was coded as ever or never because of the limited number of participants. Raw P values are shown. MET=metabolic equivalent of task

Cox proportional hazards models with age as the time scale and grouped by calendar time and cohort were used to estimate hazard ratios and 95% confidence intervals (CIs). Potential confounders were selected a priori based on the literature[13 27 28] and adjusted for in the models: ethnic group (white or non-white participants); family history of myocardial infarction or cancer (yes or no); baseline body mass index categories (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0); postmenopausal hormone use in women (premenopausal, never, former, or current use); smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day); alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day); total energy intake and modified alternate healthy eating index (in five equal groups); social integration index (in four equal groups); and baseline hypertension or hypercholesterolaemia (yes or no). Values for dietary intake, postmenopausal hormone use, smoking status, and social integration index were updated during follow-up. For the analysis of individual physical activities, we also adjusted for the total levels of all other physical activities except the type being studied (continuous). For physical activity variety, we further adjusted for total physical activity levels (continuous). Tests for trend were conducted by modelling the physical activity categories as ordinal variables. The proportional hazards assumption was

Table 2 | Associations between individual physical activities and all cause and cause specific mortality

	Hazard ratio (95% CI)*				
	Group 1 (lowest)†	Group 2†	Group 3†	Group 4 (highest)†	P_{trend}
All cause mortality:					
Walking	1 (reference)	0.90 (0.87 to 0.93)	0.83 (0.81 to 0.86)	0.83 (0.80 to 0.85)	<0.001
Jogging	1 (reference)	0.88 (0.84 to 0.92)	0.91 (0.87 to 0.95)	0.89 (0.85 to 0.94)	<0.001
Running	1 (reference)	0.90 (0.86 to 0.95)	0.88 (0.83 to 0.93)	0.87 (0.80 to 0.93)	<0.001
Bicycling	1 (reference)	0.87 (0.85, 0.90)	0.88 (0.85 to 0.91)	0.96 (0.93 to 0.99)	<0.001
Swimming	1 (reference)	0.91 (0.87, 0.94)	0.96 (0.92 to 1.00)	1.01 (0.97 to 1.05)	0.18
Tennis, squash, or racquetball	1 (reference)	0.89 (0.84, 0.94)	0.86 (0.82 to 0.91)	0.85 (0.80 to 0.89)	<0.001
Climbing flights of stairs	1 (reference)	0.93 (0.90, 0.95)	0.88 (0.86 to 0.91)	0.90 (0.87 to 0.93)	<0.001
Rowing or callisthenics	1 (reference)	0.87 (0.85, 0.89)	0.84 (0.82 to 0.87)	0.86 (0.84 to 0.89)	<0.001
Weight training or resistance exercises‡	1 (reference)	0.89 (0.85, 0.93)	0.85 (0.81 to 0.89)	0.87 (0.82 to 0.91)	<0.001
Cardiovascular disease:					
Walking	1 (reference)	0.87 (0.82, 0.92)	0.81 (0.77 to 0.86)	0.79 (0.75 to 0.84)	<0.001
Jogging	1 (reference)	0.87 (0.80, 0.94)	0.90 (0.83 to 0.99)	0.85 (0.77 to 0.95)	0.001
Running	1 (reference)	0.83 (0.75, 0.92)	0.87 (0.78 to 0.98)	0.76 (0.65 to 0.90)	<0.001
Bicycling	1 (reference)	0.92 (0.87, 0.97)	0.93 (0.88 to 0.99)	0.95 (0.89 to 1.01)	0.02
Swimming	1 (reference)	0.93 (0.86 1.01)	1.00 (0.93 to 1.08)	1.01 (0.94 to 1.09)	0.97
Tennis, squash, or racquetball	1 (reference)	0.98 (0.88 to 1.09)	0.90 (0.80 to 1.00)	0.88 (0.79 to 0.97)	0.003
Climbing flights of stairs	1 (reference)	0.95 (0.90 to 1.00)	0.89 (0.84 to 0.94)	0.91 (0.86 to 0.96)	0.001
Rowing or callisthenics	1 (reference)	0.87 (0.83 to 0.93)	0.86 (0.81 to 0.92)	0.89 (0.84 to 0.95)	<0.001
Weight training or resistance exercises‡	1 (reference)	0.95 (0.88 to 1.03)	0.89 (0.81 to 0.97)	0.91 (0.82 to 1.01)	0.008
Cancer:					
Walking	1 (reference)	0.96 (0.91 to 1.01)	0.89 (0.84 to 0.94)	0.90 (0.85 to 0.95)	<0.001
Jogging	1 (reference)	0.95 (0.88 to 1.02)	0.91 (0.84 to 0.99)	0.89 (0.81 to 0.97)	0.001
Running	1 (reference)	0.95 (0.86 to 1.04)	0.82 (0.74 to 0.92)	0.90 (0.79 to 1.01)	0.001
Bicycling	1 (reference)	0.89 (0.84 to 0.94)	0.85 (0.80 to 0.90)	0.95 (0.90 to 1.00)	0.001
Swimming	1 (reference)	0.89 (0.83 to 0.97)	0.96 (0.89 to 1.03)	1.02 (0.95 to 1.10)	0.58
Tennis, squash, or racquetball	1 (reference)	0.91 (0.82 to 1.01)	0.79 (0.71, 0.87)	0.90 (0.82 to 0.99)	<0.001
Climbing flights of stairs	1 (reference)	0.91 (0.86 to 0.96)	0.89 (0.84, 0.94)	0.92 (0.87 to 0.97)	0.001
Rowing or callisthenics	1 (reference)	0.89 (0.85 to 0.94)	0.85 (0.80, 0.90)	0.87 (0.82 to 0.93)	<0.001
Weight training or resistance exercises‡	1 (reference)	0.82 (0.75 to 0.90)	0.78 (0.71 to 0.86)	0.92 (0.84 to 1.02)	0.001
Respiratory disease:					
Walking	1 (reference)	0.85 (0.77 to 0.93)	0.69 (0.63 to 0.77)	0.73 (0.66 to 0.81)	<0.001
Jogging	1 (reference)	0.73 (0.62 to 0.86)	0.74 (0.62 to 0.89)	0.88 (0.73 to 1.07)	0.001
Running	1 (reference)	0.85 (0.70 to 1.03)	0.72 (0.57 to 0.93)	0.42 (0.28 to 0.62)	<0.001
Bicycling	1 (reference)	0.75 (0.68 to 0.83)	0.77 (0.70 to 0.86)	0.94 (0.84 to 1.04)	0.002
Swimming	1 (reference)	0.88 (0.77 to 1.02)	0.82 (0.71 to 0.96)	0.86 (0.75 to 0.99)§	0.002
Tennis, squash, or racquetball	1 (reference)	0.81 (0.65 to 1.00)§	0.81 (0.66 to 1.00)	0.56 (0.45 to 0.71)	<0.001
Climbing flights of stairs	1 (reference)	0.83 (0.76 to 0.91)	0.79 (0.71 to 0.87)	0.77 (0.69 to 0.85)	<0.001
Rowing or callisthenics	1 (reference)	0.74 (0.67 to 0.82)	0.76 (0.68 to 0.85)	0.73 (0.65 to 0.82)	<0.001
Weight training or resistance exercises‡	1 (reference)	0.74 (0.63 to 0.88)	0.86 (0.72 to 1.03)	0.84 (0.69 to 1.03)	0.009
Other causes:					
Walking	1 (reference)	0.91 (0.87 to 0.95)	0.85 (0.81 to 0.89)	0.84 (0.80 to 0.88)	<0.001
Jogging	1 (reference)	0.88 (0.83 to 0.95)	0.96 (0.89 to 1.03)	0.93 (0.86 to 1.01)	0.01
Running	1 (reference)	0.95 (0.87 to 1.03)	0.96 (0.88 to 1.06)	0.97 (0.87 to 1.09)	0.25
Bicycling	1 (reference)	0.88 (0.84 to 0.92)	0.90 (0.86 to 0.94)	0.99 (0.94 to 1.03)	0.03
Swimming	1 (reference)	0.91 (0.86 to 0.97)	0.96 (0.91 to 1.02)	1.04 (0.98 to 1.10)	0.92
Tennis, squash, or racquetball	1 (reference)	0.85 (0.77 to 0.93)	0.92 (0.84 to 1.01)	0.86 (0.78 to 0.94)	<0.001
Climbing flights of stairs	1 (reference)	0.95 (0.91 to 1.00)	0.90 (0.86 to 0.95)	0.91 (0.87 to 0.96)	<0.001
Rowing or callisthenics	1 (reference)	0.89 (0.86 to 0.93)	0.87 (0.82 to 0.91)	0.88 (0.83 to 0.92)	<0.001
Weight training or resistance exercises‡	1 (reference)	0.93 (0.87 to 0.99)	0.87 (0.81 to 0.94)	0.81 (0.75 to 0.88)	<0.001

Continued

Table 2 Continued

	Hazard ratio (95% CI)*				
	Group 1 (lowest)†	Group 2†	Group 3†	Group 4 (highest)†	P_{trend}

*Pooled results of Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020). Cox proportional hazards models used age (months) as the time scale and were stratified by calendar time and cohort. Models were adjusted for ethnic group (white or non-white participants), family history of myocardial infarction or cancer (yes or no), body mass index at baseline (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0), postmenopausal hormone use (women only; premenopausal, never, former, or current use), smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day), alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day), total energy intake (five equal groups), modified alternate healthy eating index score (five equal groups), social integration index (four equal groups), and baseline hypertension or hypercholesterolaemia (yes or no). For respiratory disease mortality, postmenopausal hormone use was coded as ever or never because of the limited number of participants. For each physical activity type, models were further adjusted for the total level of all other physical activities excluding the specific type being studied (continuous).

†For walking and climbing flights of stairs, participants were grouped into four equal categories. For other individual physical activities, because of skewed distribution towards zero, those who did not participate in the specific activity were considered the reference group and the remaining participants were grouped into three equal categories of non-zero physical activity levels. Categorisations were conducted based on the distributions within each cohort and then pooled together. In the Nurses' Health Study, median values (metabolic equivalent of task (MET) hours/week) for physical activity levels for each group (groups 1 to 4) were: 0.7, 3.1, 6.7, and 15.0 for walking; 0, 0.1, 0.7, and 4.5 for jogging; 0, 0.1, 0.6, and 7.5 for running; 0, 0.1, 1.7, and 7.0 for bicycling; 0, 0.2, 1.4, and 7.0 for swimming; 0, 0.3, 3.5, and 17.5 for tennis, squash, or racquetball; 0.2, 0.3, 0.7, and 1.3 for climbing flights of stairs; 0, 0.4, 2.3, and 7.6 for rowing or callisthenics; and 0, 0.5, 2.7, and 7.3 for weight training. Corresponding values in the Health Professionals Follow-Up Study were: 1.1, 4.2, 8.7, and 20.6 for walking; 0, 0.3, 1.6, and 6.3 for jogging; 0, 0.3, 3.7, and 19.3 for running; 0, 0.5, 2.4, and 8.8 for bicycling; 0, 0.1, 1.0, and 5.9 for swimming; 0, 0.5, 5.4, and 22.5 for tennis, squash, or racquetball; 0.1, 0.3, 0.6, and 1.1 for climbing flights of stairs; 0, 0.5, 2.1, and 6.6 for rowing or callisthenics; and 0, 0.6, 2.7, and 8.3 for weight training.

‡Pooled results of Nurses' Health Study (2000-18) and Health Professionals Follow-Up Study (1990-2020). For weight training analyses, postmenopausal hormone use was coded as ever or never because of the limited number of participants.

§Not significant after adjustment for the Benjamini-Hochberg false discovery rate. All other significance results were unchanged after adjustment for the false discovery rate; raw P_{trend} values are shown.

CI, confidence interval.

examined with a likelihood ratio test comparing models with and without multiplicative interaction terms between age and categorical physical activity variables, and no violation was found for the main exposure. Also, we fitted two multivariable adjusted models: one with total physical activity levels (continuous) and the other with total physical activity levels and physical activity variety (categorical) and then used the likelihood ratio test to examine whether the model including physical activity variety had a better fit than that including total physical activity levels only. We also examined the joint associations of total physical activity levels and physical activity variety with mortality: participants were grouped into nine subgroups based on combinations of total physical activity levels (in three equal groups) and physical activity variety score (in three equal groups). Participants in the lowest group for both categories were considered the reference group. Interactions were tested by the likelihood ratio test comparing models with and without product terms between total physical activity level and physical activity variety categories.

To explore the dose-response relation between total and individual physical activity levels and mortality, we fitted restricted cubic spline regressions with four knots,[29] adjusting for the same covariates as in the main analysis and by using the SAS macro % LGTPHCURV9. Data were truncated at the 99th centile to limit the influence of extreme values. For total physical activity, walking, and climbing flights of stairs, we set the fifth, 35th, 65th, and 95th centiles as the four knots. For other individual physical activities, because of the skewed distribution towards zero, we set the fifth, 35th, 65th, and 95th centiles among the non-zero values. The minimum values of physical activity levels were set as the reference for each spline curve. We used the likelihood ratio test for tests for non-linearity, comparing the model with only the linear term with the model with the linear and cubic spline terms.

To test whether our findings were influenced by stopping updating physical activity after an intermediate outcome, we reanalysed the data with continuously updated physical activity data. Because recent physical activity practices might affect mortality more than past practices,[30] we examined the associations based on the simple updated physical activity levels. All statistical analyses were performed with SAS software, version 9.4 (SAS Institute). A two sided P value <0.05 was considered significant. We applied the Benjamini-Hochberg false discovery rate adjustment to account for multiple testing in the association analyses between total physical activity, individual physical activities, and physical activity variety, and mortality.

Patient and public involvement

We did not have the infrastructure, resources, funding, or time to involve the public in study design, interpretation of results, or publication.

Results

Descriptive characteristics

In the pooled dataset, participants with higher total physical activity levels had a lower baseline prevalence of hypertension, hypercholesterolaemia, and body mass index, higher alcohol and energy intake, better diet quality, higher social integration and physical activity variety, and were less likely to smoke (table 1). Online supplemental table 2 shows the cohort specific characteristics of participants in the two studies. The Spearman coefficient between total physical activity levels and variety was 0.75

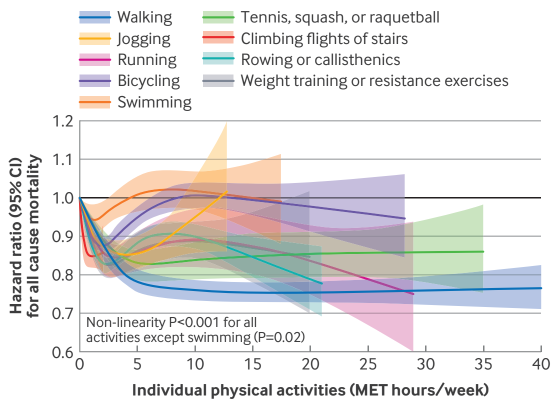

Figure 2 | Dose-response relations between individual physical activities and all cause mortality (overview of dose-response curves shown in Figure 3). Pooled results from Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020), except for weight training (Nurses' Health Study 2000-18; Health Professionals Follow-Up Study 1990-2020). Data were truncated at the 99th centile value. Models were stratified by age (months), calendar time, and cohort, and were adjusted for ethnic group (white or non-white participants), family history of myocardial infarction or cancer (yes or no), body mass index at baseline (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0), postmenopausal hormone use (women only; premenopausal, never, former, or current use), smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day), alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day), total energy intake (five equal groups), modified alternate healthy eating index score (five equal groups), social integration index (four equal groups), and baseline hypertension or hypercholesterolaemia (yes or no). In the models for respiratory disease mortality and analyses for weight training, postmenopausal hormone use was coded as ever or never because of the limited number of participants. For each physical activity type, models were further adjusted for the total level of all other physical activities excluding the specific type being studied (continuous). Raw P values are shown. Detailed dose-response curves for each activity are shown in Figure 3. MET=metabolic equivalent of task

in the Nurses' Health Study and 0.70 in the Health Professionals Follow-Up Study. For individual physical activities, the Spearman coefficients were small to modest, except for the correlation between jogging and running which was relatively higher (0.42 in Nurses' Health Study and 0.47 in Health Professionals Follow-Up Study; online supplemental table 3). Walking was the most frequently engaged activity in both cohorts, and participants in the Health Professionals Follow-Up Study were more likely to jog and run than those in the Nurses' Health Study (online supplemental figure 1). For most individual physical activities except for swimming, participants in the highest group (group 4) had a lower body mass index and baseline prevalence of hypertension than those in the lowest group (group 1; online supplemental table 4).

Physical activity amount and mortality

During 2 431 318 person years of follow-up, 38 847 deaths were recorded, with 9901 from cardiovascular disease, 10 719 from cancer, and 3159 from respiratory disease. Total physical activity was associated with lower mortality (online supplemental table 5). The lower risk of death from cardiovascular disease, cancer, and respiratory disease largely plateaued after reaching about 20 MET hours/week of total physical activity, whereas the lower risk of death from other causes was weaker (all P<0.001 for non-linearity, figure 1).

Compared with those in the lowest group (group 1) for the specific physical activity, the multivariable adjusted hazard ratios for all cause mortality for participants in the highest group (group 4) were 0.83 (95% CI 0.80 to 0.85) for walking, 0.89 (0.85 to 0.94) for jogging, 0.87 (0.80 to 0.93) for running, 0.96 (0.93, 0.99) for bicycling, 1.01 (0.97, 1.05) for swimming, 0.85 (0.80 to 0.89) for tennis, squash, or racquetball, 0.90 (0.87 to 0.93) for climbing flights of stairs, 0.86 (0.84 to 0.89) for rowing or callisthenics, and 0.87 (0.82 to 0.91) for weight training or resistance exercises (P_{trend}<0.001 for all except swimming (P_{trend}=0.18); table 2).

Figure 2 shows that the attainable levels of energy expenditure varied substantially for different activities in our study population, ranging from 2.1 MET hours/week for climbing flights of stairs to >40 MET hours/week for walking. We found non-linear associations between various types of physical activities and all cause mortality (P=0.02 for non-linearity for swimming and P<0.001 for all other activities; figure 3). The reduction in the risk of all cause mortality seemed to plateau at about 0.75 MET hours/week for climbing flights of stairs, 5 MET hours/week for tennis, squash, or racquetball, 7.5 MET hours/week for walking, and 7.5 MET hours/week for weight training or resistance exercises. For swimming, bicycling, and jogging, inverse associations with all cause mortality were apparent up to about 2.5, 7.5 and 9 MET hours/week, respectively; beyond these thresholds, the associations were no longer significant. For running and rowing or callisthenics, a sharp reduction in risk was seen up to about 3 and 2.5 MET hours/week, respectively, followed by a continued, although slower, decline with higher activity levels.

Although the range of physical activity levels was generally broader in the Health Professionals Follow-Up Study than in the Nurses' Health Study, the associations for total and most individual physical activities were consistent in both direction and shape for the two cohorts within comparable physical activity ranges (online supplemental table 6 and figure 2), supporting the validity of the pooled analysis approach. However, an inverse association at higher levels of bicycling (ie, 7.5 MET hours/week) was found in the Health Professionals

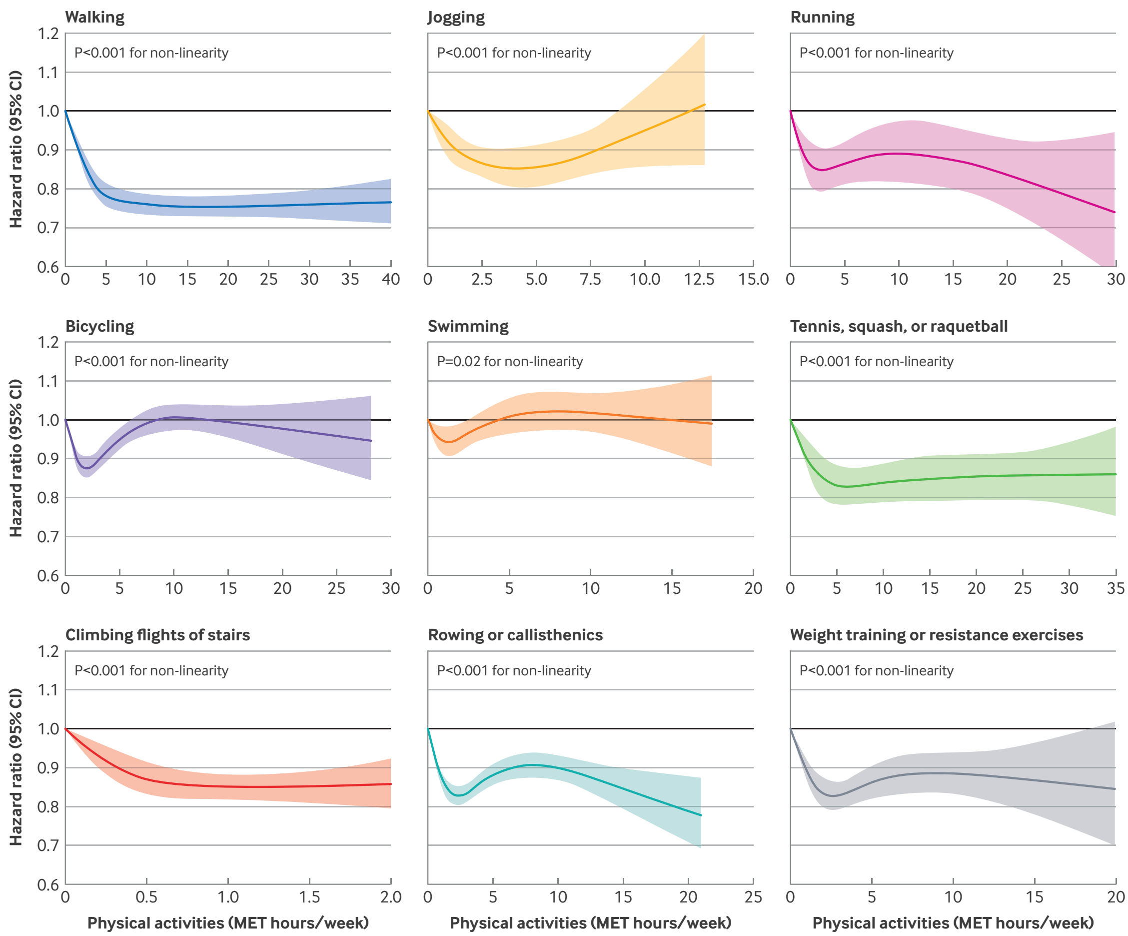

Figure 3 | Dose-response relations between individual physical activities and all cause mortality. Pooled results from Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020), except for weight training (Nurses' Health Study 2000-18; Health Professionals Follow-Up Study 1990-2020). Data were truncated at the 99th centile value. Models were stratified by age (months), calendar time, and cohort, and were adjusted for ethnic group (white or non-white participants), family history of myocardial infarction or cancer (yes or no), body mass index at baseline (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0), postmenopausal hormone use (women only; premenopausal, never, former, or current use), smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day), alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day), total energy intake (five equal groups), modified alternate healthy eating index score (five equal groups), social integration index (four equal groups), and baseline hypertension or hypercholesterolaemia (yes or no). In the models for respiratory disease mortality and analyses for weight training, postmenopausal hormone use was coded as ever or never because of the limited number of participants. For each physical activity type, models were further adjusted for the total level of all other physical activities excluding the specific type being studied (continuous). Raw P values are shown. MET=metabolic equivalent of task

Follow-Up Study but not in the Nurses' Health Study.

The associations between walking, jogging, bicycling, and rowing or callisthenics and cause specific mortality were similar to those observed for all cause mortality, whereas the associations for other activities differed depending on the cause of death (table 2 and online supplemental figure 3). For cardiovascular disease and respiratory disease mortality, running, tennis, squash, or racquetball, climbing flights of stairs, and weight training or resistance exercises were significantly associated with lower risks, with these associations appearing more linear (all P>0.05 for non-linearity and P<0.05 for linearity; exact P values are shown in online supplemental figure 3). Also, swimming had a significant non-linear association with respiratory disease mortality (P=0.003 for non-linearity) only but was not associated with mortality from other specific causes. Most physical activities, except swimming, showed significant non-linear associations with cancer mortality (all P<0.05 for non-linearity).

For specific activities in the Nurses' Health Study, lower intensity exercise was associated with lower all cause mortality, especially for cancer mortality (both P_{trend}=0.001; online supplemental table 7). Also, other vigorous activity was associated with lower mortality from causes other than cancer (all P_{trend}<0.001, except for cancer mortality (P_{trend}=0.12)). For specific activities in the Health Professionals

Table 3 | Associations between physical activity variety score and all cause and cause specific mortality*

	Physical activity variety score (hazard ratio (95% CI))					
	Group 1 (lowest)	Group 2	Group 3	Group 4	Group 5 (highest)	P_{trend}
All cause mortality:						
No of person years	466 087	506 547	466 901	493 632	486 708	
No of patients	10 602	8190	7573	6525	5465	
Model 1†	1 (reference)	0.86 (0.84 to 0.89)	0.85 (0.83 to 0.88)	0.81 (0.78 to 0.83)	0.79 (0.77 to 0.82)	<0.001
Model 2‡	1 (reference)	0.87 (0.84 to 0.89)	0.86 (0.83 to 0.89)	0.82 (0.79 to 0.85)	0.81 (0.78 to 0.85)	<0.001
Cardiovascular disease:						
No of patients	2861	2071	1958	1607	1251	
Model 1†	1 (reference)	0.83 (0.79 to 0.88)	0.86 (0.81 to 0.92)	0.80 (0.75 to 0.85)	0.77 (0.72 to 0.83)	<0.001
Model 2‡	1 (reference)	0.85 (0.80 to 0.90)	0.89 (0.83 to 0.95)	0.83 (0.78 to 0.90)	0.83 (0.76 to 0.90)	<0.001
Cancer:						
No of patients	2676	2271	2063	1923	1684	
Model 1†	1 (reference)	0.92 (0.87 to 0.97)	0.86 (0.81 to 0.91)	0.87 (0.82 to 0.93)	0.86 (0.80 to 0.92)	<0.001
Model 2‡	1 (reference)	0.92 (0.87 to 0.97)	0.87 (0.81 to 0.92)	0.88 (0.82 to 0.94)	0.87 (0.80 to 0.94)	0.001
Respiratory disease:						
No of patients	1050	656	603	465	332	
Model 1†	1 (reference)	0.72 (0.65 to 0.80)	0.72 (0.65 to 0.80)	0.61 (0.55 to 0.69)	0.52 (0.46 to 0.60)	<0.001
Model 2‡	1 (reference)	0.74 (0.67 to 0.82)	0.76 (0.68 to 0.85)	0.66 (0.58 to 0.74)	0.59 (0.50 to 0.69)	<0.001
Other causes:						
No of patients	4015	3192	2949	2530	2198	
Model 1†	1 (reference)	0.90 (0.86 to 0.95)	0.89 (0.85 to 0.94)	0.84 (0.79 to 0.88)	0.85 (0.80 to 0.90)	<0.001
Model 2‡	1 (reference)	0.89 (0.85 to 0.94)	0.88 (0.84 to 0.93)	0.82 (0.78 to 0.87)	0.82 (0.77 to 0.88)	<0.001

*Pooled results of Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020). The analysis of physical activity variety score was limited to 111 373 participants reporting any physical activity (2 419 876 person years). The physical activity variety score was calculated as the sum of individual physical activities consistently performed (one point per physical activity meeting the predefined threshold; otherwise 0). The cumulative average during follow-up assessed long term physical activity variety. Groupings were conducted based on the distributions within each cohort and then pooled together. Median values of physical activity variety score in each group (groups 1-5) were 0.6, 1.2, 1.8, 2.3, and 3.2 in the Nurses' Health Study and 1.0, 1.8, 2.3, 3.0, and 4.0 in the Health Professionals Follow-Up Study. All significance results were unchanged after adjustment for the Benjamini-Hochberg false discovery rate; raw P_{trend} values are shown.

†Cox proportional hazards models used age (months) as the time scale and were stratified by calendar time and cohort. Models were adjusted for ethnic group (white or non-white participants), family history of myocardial infarction or cancer (yes or no), body mass index at baseline (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0), postmenopausal hormone use (women only; premenopausal, never, former, or current use), smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day), alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day), total energy intake (five equal groups), modified alternate healthy eating index score (five equal groups), social integration index (four equal groups), and baseline hypertension or hypercholesterolaemia (yes or no). For respiratory disease mortality, postmenopausal hormone use was coded as ever or never because of the limited number of participants.

‡Model 2 was further adjusted for total physical activity level (continuous) based on model 1.

CI, confidence interval.

Follow-Up Study, heavy outdoor work showed an inverse association with respiratory disease mortality (P_{trend}=0.003).

Physical activity variety and mortality

The physical activity variety score was inversely associated with all cause mortality, and this association remained significant after adjusting for total physical activity (P_{trend}<0.001; table 3 and online supplemental table 8). Compared with the lowest group (group 1), the highest group (group 5) for the physical activity variety score was associated with a 19% lower all cause mortality (95% CI 0.78 to 0.85) and 13-41% lower mortality from cardiovascular disease, cancer, respiratory disease, and other causes. The model fit was improved by adding physical activity variety to the model with total physical activity levels and other covariates (P<0.001 for likelihood ratio test in the pooled analysis).

Amount and variety of physical activity

Compared with the reference group, participants ranked highest for both total physical activity level and variety had 21% lower mortality (95% CI 0.76 to 0.82; figure 4). With further adjustment of total physical activity levels within each group, in the highest group the hazard ratio decreased to 0.75 (95% CI 0.72 to 0.79; online supplemental table 9). Higher physical activity variety scores within each group of total physical activity level were associated with lower all cause mortality, but this trend was less consistent for specific causes (online supplemental table 10). We found no interactions between total physical activity level and physical activity variety score on mortality.

Sensitivity analyses

The results were largely similar when we continuously updated the physical activity data (online supplemental tables 11–13) or used the simple

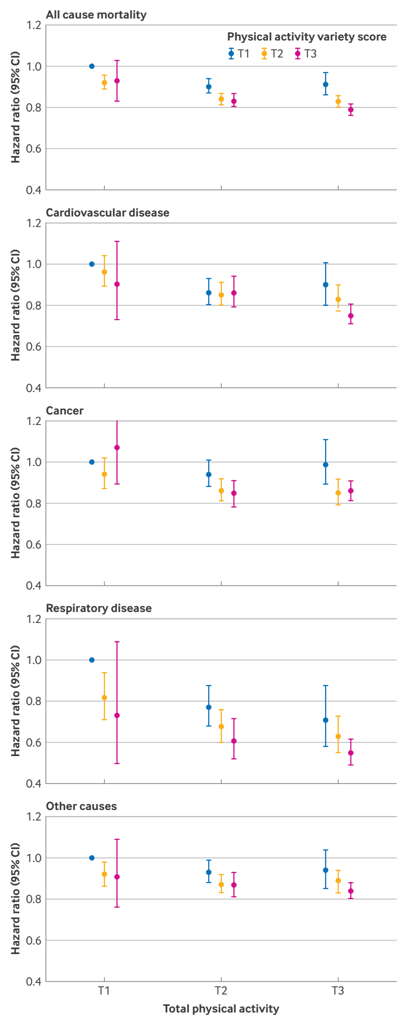

Figure 4 | Joint associations of total physical activity level and physical activity variety with all cause and cause specific mortality. Pooled results of Nurses' Health Study (1986-2018) and Health Professionals Follow-Up Study (1986-2020). Cox proportional hazards models used age (months) as the time scale and were stratified by calendar time and cohort. Models were adjusted for ethnic group (white or non-white participants), family history of myocardial infarction or cancer (yes or no), body mass index at baseline (<23.0, 23.0-24.9, 25.0-29.9, 30.0-34.9, or ≥35.0), postmenopausal hormone use (women only; premenopausal, never, former, or current use), smoking status (never smoked, past smoker, currently smoke 1-14, 15-24, or ≥25 cigarettes/day), alcohol intake (0, 0.1-4.9, 5.0-9.9, 10.0-14.9, 15.0-29.9, or ≥30.0 g/day), total energy intake (five equal groups), modified alternate healthy eating index score (five equal groups), social integration index (four equal groups), and baseline hypertension or hypercholesterolaemia (yes or no). For respiratory disease mortality, postmenopausal hormone use was coded as ever or never because of the limited number of participants. Participants were grouped into nine subgroups based on combinations of total physical activity level (three equal groups) and physical activity variety score (three equal groups). Participants in the lowest group for both total physical activity level and physical activity variety score were considered the reference group. All P>0.05 for interaction. T1=lowest group; T2=medium group; T3=highest group

updated physical activity levels (online supplemental tables 14–16).

Discussion

Principal findings

In this study, we found that the total physical activity and most individual physical activities were associated with lower mortality in a non-linear manner, suggesting the presence of a potential threshold for the beneficial effects of physical activity. Also, a simple physical activity variety score was associated with lower mortality, independent of total physical activity levels, suggesting that long term engagement in multiple types of physical activity may have additional health benefits on longevity.

Comparison with other studies

Our finding that total physical activity was linked to lower mortality aligns with previous studies.[3] The possibility of distinct physiological effects of different physical activities has received increasing attention. Bicycling and running have different ventilatory responses, blood flow, skeletal muscle oxidative capacity, and central and peripheral innervation.[31] Also, several studies found significant differences between aerobic exercises and resistance training. In a 26 week randomised trial in 160 older adults with obesity,[8] the aerobic group showed greater increases in peak oxygen consumption but fewer improvements in strength compared with the resistance group, whereas the resistance group had smaller decreases in lean mass and bone mineral density. Another 26 week randomised trial of 124 healthy participants showed that endurance and interval training, rather than resistance training, increased telomerase activity and telomere length.[32] A recent study indicated the advantage of aerobic exercises over resistance training in improving the risk profiles for cardiovascular disease in adults with overweight or obesity.[7] Research evaluating the health effects of engagement in multiple commonly practised physical activity types, however, is scarce.[33]

Although few studies have evaluated various physical activities simultaneously, existing data suggest that walking,[9 12 14 15] climbing stairs,[14] aerobic exercises,[11–14] and racquet sports[11–13] are associated with lower mortality after accounting for other physical activities. Most studies, however, only examined the influence of any participation in specific activities with one measurement at baseline. Our study showed the non-linear relation between long term engagement in these physical activities and mortality. A meta-analysis reported that running or jogging was associated with mortality, independent of their duration,[34] although we found that running, rather than jogging, was linearly associated with mortality from cardiovascular and respiratory disease. This observation may support the notion that cardiorespiratory fitness is more responsive to the intensity rather than the volume of physical activity.[35] Our findings confirmed the potential benefits of weight training on longevity, as reported previously.[36] Evidence linking bicycling to mortality is controversial. A meta-analysis of 17 prospective studies reported a linear relation between bicycling and all cause mortality, with a 9% lower risk for each increase in bicycling of 5 MET hours/week.[37] Updated evidence, however, indicated either a non-linear relation[9] or no association.[14 15] The inability to differentiate between the purpose of bicycling (active commuting or recreational) or to capture variations during follow-up[38] may contribute to these inconsistencies. Our study focused on long term leisure time bicycling and found a reduction in all cause mortality before reaching 7.5 MET hours/week (ie, 64 min/week), with the lowest risk found at about 2.5 MET hours/week. Given the downward trend in risk in the Health Professionals Follow-Up Study and the suggestive upward trend in the Nurses' Health Study, more studies are needed to confirm the dose-response relation between bicycling and mortality in men and women, and to clarify the underlying biological mechanisms.

We found that higher levels of swimming activities were not associated with a lower all cause mortality, adding to the varied findings in this area.[10–14] Self-reported swimming duration, even when specified as lap swimming, may correspond to a wide range of actual energy expenditures because of variations in exercise intensity.[39] For example, individuals may report similar swimming durations regardless of whether they swim vigorously or casually. This potential misclassification of true energy expenditure in swimming, particularly among those reporting longer swimming durations, may bias the observed associations towards the null. Therefore, further research on both length of time spent swimming and swimming intensity is needed to clarify their relation with mortality.

Little evidence exists about the potential health effects of physical activity variety. Several studies found that engagement in both aerobic exercises and resistance training enhanced physical function more effectively than either type alone.[8 40] Findings among male athletes suggested participation in multiple collegiate sports was associated with higher levels of physical activity in later life than participation in one sport.[41] These data imply a potential extra advantage of engagement in multiple physical activities. Our study provides longitudinal evidence indicating a link between greater variety in physical activities and longevity. Consistent with previous studies,[42] we found that the health benefits of most individual physical activities plateaued at certain levels. Individuals who engage in multiple physical activities may maximise the health benefits by engaging with each individual activity within the levels of the beneficial threshold. The finding that a greater variety of physical activities predicted lower all cause mortality among individuals within each category of total physical activity level indicated that engaging in multiple types of physical activities may exert additional health benefits independent of total physical activity levels. Notably, our approach, focusing on physical activity variety, did not specify fixed combinations of physical activity types because individuals may choose different types of physical activity over time according to their personal preferences and physical condition. Given the potential heterogeneous associations between specific types of physical activity and cause specific mortality, however, future studies exploring potential synergistic effects of different physical activities may help to refine the current guidelines on the health benefits of physical activity.

Strengths and limitations of this study

The strengths of our study included the large sample sizes and long follow-up periods with repeated physical activity measurements, allowing us to capture long term practices of multiple physical activities.

The study had several limitations. Firstly, the physical activity data were self-reported, inevitably introducing measurement errors. The prospective study design, however, may mean that the errors were largely non-differential because determining the outcomes was unrelated to the measurement errors. Secondly, not all types of physical activity were assessed in the baseline questionnaires for both cohorts. Some activities (eg, weight training or resistance exercises, or outdoor work) were only collected in later questionnaire cycles or in one cohort. Although we restricted analyses for these activities to participants and questionnaire cycles with available data, this approach may have limited the sample sizes and comparability between the cohorts. Nevertheless, we maximised the use of the available information by examining associations between each physical activity type and mortality within the relevant cohort, or in pooled analyses where applicable, providing new insights into the dose-response relations of specific activities that were previously underexplored. Thirdly, because MET scores are assigned assuming active engagement, the lack of information on intensity may cause misclassification of true energy expenditures, particularly for activities such as swimming, which could bias the observed associations towards the null. Fourthly, despite efforts, such as applying lag analyses, the possibility of reverse causation cannot be eliminated. This limitation is particularly relevant for respiratory disease, which can have longstanding insidious symptoms that may appear long before diagnosis. Nevertheless, we found similar associations between physical activity and mortality other than for respiratory disease (online supplemental table 17). Fifthly, because only women participated in the Nurses' Health Study and only men participated in the Health Professionals Follow-Up Study, our cohort specific analyses were equivalent to sex specific analyses. Potential differences should be confirmed and further explored in other studies that include both men and women. Lastly, although potential misclassification may arise from missing assessments of physical activity during follow-up, this effect should be minimal, given that 83% of participants had complete physical activity data or no more than two cycles with missing data, and we calculated cumulative average physical activity levels based on all available cycles. Also, our participants were mainly white health professionals, which might limit the generalisability of our findings to other populations.

Conclusions

Our findings suggest that an active lifestyle and engagement in multiple physical activities may facilitate long term survival.

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Contributors QS, YH, JH, and HH participated in project conception and development of research methods. QS obtained funding and provided oversight. HH, JH, YH, and QS analysed the data and performed the analyses. JH, HH, and QS drafted the article. QS, YH, MS, DHL, YZ, EG, and FBH contributed to data interpretation and critical review of the report. All authors provided final approval of the version to be published. The senior authors (YH and QS) attest that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. QS is the guarantor. Transparency: The lead author (the guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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Ethics approval This study involves human participants and the study protocol was approved by the institutional review boards of the Brigham and Women's Hospital and Harvard T H Chan School of Public Health, and those of participating registries, as required. The institutional review boards allowed participants' completion of questionnaires to be considered as implied consent.

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REFERENCES

1 Piercy KL, Troiano RP, Ballard RM, *et al*. The Physical Activity Guidelines for Americans. JAMA 2018;320:2020–8. 10.1001/jama.2018.14854
2 Lloyd-Jones DM, Allen NB, Anderson CAM, *et al*. Life's Essential 8: Updating and Enhancing the American Heart Association's Construct of Cardiovascular Health: A Presidential Advisory From the American Heart Association. Circulation 2022;146:e18–43. 10.1161/CIR.0000000000001078
3 Garcia L, Pearce M, Abbas A, *et al*. Non-occupational physical activity and risk of cardiovascular disease, cancer and mortality outcomes: a dose-response meta-analysis of large prospective studies. Br J Sports Med 2023;57:979–89. 10.1136/bjsports-2022-105669
4 Pearce M, Garcia L, Abbas A, *et al*. Association Between Physical Activity and Risk of Depression: A Systematic Review and Meta-analysis. JAMA Psychiatry 2022;79:550–9. 10.1001/jamapsychiatry.2022.0609
5 Cunningham C, O' Sullivan R, Caserotti P, *et al*. Consequences of physical inactivity in older adults: A systematic review of reviews and meta-analyses. Scand J Med Sci Sports 2020;30:816–27. 10.1111/sms.13616
6 Oja P, Memon AR, Titze S, *et al*. Health Benefits of Different Sports: a Systematic Review and Meta-Analysis of Longitudinal and Intervention Studies Including 2.6 Million Adult Participants. Sports Med Open 2024;10:46. 10.1186/s40798-024-00692-x
7 Lee D-C, Brellenthin AG, Lanningham-Foster LM, *et al*. Aerobic, resistance, or combined exercise training and cardiovascular risk profile in overweight or obese adults: the CardioRACE trial. Eur Heart J 2024;45:1127–42. 10.1093/eurheartj/ehad827
8 Villareal DT, Aguirre L, Gurney AB, *et al*. Aerobic or Resistance Exercise, or Both, in Dieting Obese Older Adults. N Engl J Med 2017;376:1943–55. 10.1056/NEJMoa1616338
9 Porter AK, Cuthbertson CC, Evenson KR. Participation in specific leisure-time activities and mortality risk among U.S. adults. Ann Epidemiol 2020;50:27–34. 10.1016/j.annepidem.2020.06.006
10 Bergwall S, Acosta S, Ramne S, *et al*. Leisure-time physical activities and the risk of cardiovascular mortality in the Malmö diet and Cancer study. BMC Public Health 2021;21:1948. 10.1186/s12889-021-11972-6

11 Oja P, Kelly P, Pedisic Z, *et al*. Associations of specific types of sports and exercise with all-cause and cardiovascular-disease mortality: a cohort study of 80 306 British adults. Br J Sports Med 2017;51:812–7. 10.1136/bjsports-2016-096822
12 Watts EL, Matthews CE, Freeman JR, *et al*. Association of Leisure Time Physical Activity Types and Risks of All-Cause, Cardiovascular, and Cancer Mortality Among Older Adults. JAMA Netw Open 2022;5:e2228510. 10.1001/jamanetworkopen.2022.28510
13 Schnohr P, O'Keefe JH, Holtermann A, *et al*. Various Leisure-Time Physical Activities Associated With Widely Divergent Life Expectancies: The Copenhagen City Heart Study. Mayo Clin Proc 2018;93:1775–85. 10.1016/j.mayocp.2018.06.025
14 Sheehan CM, Li L. Associations of Exercise Types with All-Cause Mortality among U.S. Adults. Med Sci Sports Exerc 2020;52:2554–62. 10.1249/MSS.0000000000002406
15 Duarte Junior MA, Martínez-Gómez D, Pintos-Carrillo S, *et al*. Associations of physical activity type, volume, intensity, and changes over time with all-cause mortality in older adults: The Seniors-ENRICA cohorts. Scand J Med Sci Sports 2024;34:e14536. 10.1111/sms.14536
16 Ainsworth BE, Haskell WL, Leon AS, *et al*. Compendium of physical activities: classification of energy costs of human physical activities. Med Sci Sports Exerc 1993;25:71–80. 10.1249/00005768-199301000-00011
17 Pernar CH, Chomistek AK, Barnett JB, *et al*. Validity and Relative Validity of Alternative Methods of Assessing Physical Activity in Epidemiologic Studies: Findings From the Men's Lifestyle Validation Study. Am J Epidemiol 2022;191:1307–22. 10.1093/aje/kwac051
18 Al-Shaar L, Pernar CH, Chomistek AK, *et al*. Reproducibility, Validity, and Relative Validity of Self-Report Methods for Assessing Physical Activity in Epidemiologic Studies: Findings From the Women's Lifestyle Validation Study. Am J Epidemiol 2022;191:696–710. 10.1093/aje/kwab294
19 Chasan-Taber S, Rimm EB, Stampfer MJ, *et al*. Reproducibility and validity of a self-administered physical activity questionnaire for male health professionals. Epidemiology 1996;7:81–6. 10.1097/00001648-199601000-00014
20 Wolf AM, Hunter DJ, Colditz GA, *et al*. Reproducibility and validity of a self-administered physical activity questionnaire. Int J Epidemiol 1994;23:991–9. 10.1093/ije/23.5.991
21 Sotos-Prieto M, Bhupathiraju SN, Mattei J, *et al*. Association of Changes in Diet Quality with Total and Cause-Specific Mortality. N Engl J Med 2017;377:143–53. 10.1056/NEJMoa1613502
22 Tsai AC, Lucas M, Kawachi I. Association Between Social Integration and Suicide Among Women in the United States. JAMA Psychiatry 2015;72:987–93. 10.1001/jamapsychiatry.2015.1002
23 Tsai AC, Lucas M, Sania A, *et al*. Social integration and suicide mortality among men: 24-year cohort study of U.S. health professionals. Ann Intern Med 2014;161:85–95. 10.7326/M13-1291
24 Rich-Edwards JW, Corsano KA, Stampfer MJ. Test of the National Death Index and Equifax Nationwide Death Search. Am J Epidemiol 1994;140:1016–9. 10.1093/oxfordjournals.aje.a117191
25 Stampfer MJ, Willett WC, Speizer FE, *et al*. Test of the National Death Index. Am J Epidemiol 1984;119:837–9. 10.1093/oxfordjournals.aje.a113804
26 Song M, Zhou X, Pazaris M, *et al*. The missing covariate indicator method is nearly valid almost always. arXiv 2021;211100138. 10.48550/arXiv.2111.00138
27 Lee DH, Rezende LFM, Ferrari G, *et al*. Physical activity and all-cause and cause-specific mortality: assessing the impact of reverse causation and measurement error in two large prospective cohorts. Eur J Epidemiol 2021;36:275–85. 10.1007/s10654-020-00707-3
28 Ji H, Gulati M, Huang TY, *et al*. Sex Differences in Association of Physical Activity With All-Cause and Cardiovascular Mortality. J Am Coll Cardiol 2024;83:783–93. 10.1016/j.jacc.2023.12.019
29 Durrleman S, Simon R. Flexible regression models with cubic splines. Stat Med 1989;8:551–61. 10.1002/sim.4780080504
30 Paffenbarger RS Jr, Hyde RT, Wing AL, *et al*. The association of changes in physical-activity level and other lifestyle characteristics with mortality among men. N Engl J Med 1993;328:538–45. 10.1056/NEJM199302253280804
31 Millet GP, Vleck VE, Bentley DJ. Physiological differences between cycling and running: lessons from triathletes. Sports Med 2009;39:179–206. 10.2165/00007256-200939030-00002
32 Werner CM, Hecksteden A, Morsch A, *et al*. Differential effects of endurance, interval, and resistance training on telomerase activity and telomere length in a randomized, controlled study. Eur Heart J 2019;40:34–46. 10.1093/eurheartj/ehy585
33 Oja P, Titze S, Kokko S, *et al*. Health benefits of different sport disciplines for adults: systematic review of observational and intervention studies with meta-analysis. Br J Sports Med 2015;49:434–40. 10.1136/bjsports-2014-093885
34 Pedisic Z, Shrestha N, Kovalchik S, *et al*. Is running associated with a lower risk of all-cause, cardiovascular and cancer mortality, and is the more the better? A systematic review and meta-analysis. Br J Sports Med 2020;54:898–905. 10.1136/bjsports-2018-100493
35 Ross R, Blair SN, Arena R, *et al*. Importance of Assessing Cardiorespiratory Fitness in Clinical Practice: A Case for Fitness as a Clinical Vital Sign: A Scientific Statement From the American Heart Association. Circulation 2016;134:e653–99. 10.1161/CIR.0000000000000461
36 Momma H, Kawakami R, Honda T, *et al*. Muscle-strengthening activities are associated with lower risk and mortality in major non-communicable diseases: a systematic review and meta-analysis of cohort studies. Br J Sports Med 2022;56:755–63. 10.1136/bjsports-2021-105061
37 Zhao Y, Hu F, Feng Y, *et al*. Association of Cycling with Risk of All-Cause and Cardiovascular Disease Mortality: A Systematic Review and Dose-Response Meta-analysis of Prospective Cohort Studies. Sports Med 2021;51:1439–48. 10.1007/s40279-021-01452-7
38 Aggio D, Papacosta O, Lennon LT, *et al*. Tracking of sport and exercise types from midlife to old age: a 20-year cohort study of British men. Eur Rev Aging Phys Act 2018;15:16. 10.1186/s11556-018-0205-y
39 Chomistek AK, Henschel B, Eliassen AH, *et al*. Frequency, Type, and Volume of Leisure-Time Physical Activity and Risk of Coronary Heart Disease in Young Women. Circulation 2016;134:290–9. 10.1161/CIRCULATIONAHA.116.021516
40 Colleluori G, Aguirre L, Phadnis U, *et al*. Aerobic Plus Resistance Exercise in Obese Older Adults Improves Muscle Protein Synthesis and Preserves Myocellular Quality Despite Weight Loss. Cell Metab 2019;30:261–73. 10.1016/j.cmet.2019.06.008
41 Wasfy MM, Siam UT, Gustus SK, *et al*. Long-term follow up from the Harvard Alumni Health Study: collegiate sport participation in males is associated with higher physical activity throughout midlife. Br J Sports Med 2025;59:791–7. 10.1136/bjsports-2024-109255
42 Lee DH, Rezende LFM, Joh H-K, *et al*. Long-Term Leisure-Time Physical Activity Intensity and All-Cause and Cause-Specific Mortality: A Prospective Cohort of US Adults. Circulation 2022;146:523–34. 10.1161/CIRCULATIONAHA.121.058162

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