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Associations of vigorous physical activity with all-cause, cardiovascular and cancer mortality among 64 913 adults

Juan Pablo Rey Lopez,[1] Klaus Gebel,[2,3] Debbie Chia,[1] Emmanuel Stamatakis[1,4]

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[1]Prevention Research Collaboration, Charles Perkins Centre, Sydney School of Public Health, The University of Sydney, Sydney, New South Wales, Australia
[2]School of Behavioural and Health Sciences, Australian Catholic University, Sydney, New South Wales, Australia
[3]Centre for Chronic Disease Prevention, College of Public Health, Medical and Veterinary Sciences, James Cook University, Cairns, Queensland, Australia
[4]Charles Perkins Centre, Epidemiology Unit, The University of Sydney, Sydney, New South Wales, Australia

Correspondence to
Dr Juan Pablo Rey Lopez; juan.reylopez@sydney.edu.au

ABSTRACT

Background Physical activity recommendations state that for the same energy expenditure, moderate-to-vigorous physical activities (MVPAs) produce similar health benefits. However, few epidemiological studies have tested this hypothesis.

Design We examined whether, compared with moderate, vigorous activity was associated with larger mortality risk reductions.

Methods Data from 11 cohorts of the Health Survey for England and the Scottish Health Survey, collected from 1994 to 2011 (mean (SD) follow-up, 9.0 (3.6) years). Adults aged ≥30 years reported MVPA and linkage to mortality records. Exposure was the proportion of self-reported weighted MVPA through vigorous activity. Outcomes were all-cause, cardiovascular disease (CVD) and cancer mortality.

Results Among 64 913 adult respondents (44% men, 56% women, mean (SD) age, 49.8 (13.6) years), there were 5064 deaths from all-causes, 1393 from CVD and 1602 from cancer during 435 743 person-years of follow-up. Compared with those who reported no vigorous physical activity, and holding constant the volume of weighted MVPA, vigorous activity was associated with additional reductions in mortality risk. For all-cause mortality, the adjusted HR was HR=0.84 (95% CI 0.71, 0.99) and HR=0.84 (95% CI 0.76, 0.94) among those who reported between >0% and<30%, or ≥30% of their activity as vigorous, respectively. For CVD and cancer mortality, point estimates showed similar beneficial associations yet CIs were wider and crossed unity.

Conclusion Vigorous activities were associated with larger reductions in mortality risk than activities of moderate intensity, but no evidence of dose–response effects was found.

What is already known?

- ► A higher volume of physical activity is associated with lower mortality risk, but it is unknown whether vigorous activity may yield larger reductions on mortality risk than energy-matched activities of lower intensity.

What is the new finding?

- ► In this cohort, vigorous physical activity was associated with larger reductions on all-cause mortality risk than activities of lower intensity.
- ► No evidence of dose-response effects on reductions of mortality was found with vigorous activities. For cancer mortality risk, no conclusive evidence was found about the role of vigorous activities.

BACKGROUND

The health benefits of physical activity are well established.[1] Physical inactivity is the fourth leading risk factor for global mortality,[2] causing an estimated 5.3 million deaths per year.[3] Guidelines from the USA,[4] UK,[5] Australia[6] and the WHO[7] recommend that to achieve significant health benefits, including a lower mortality risk, adults should accumulate at least 150 min of moderate activity (3–5.9 metabolic equivalent tasks, METs), or 75 min of vigorous activity (≥6 METs) per week, or a combination of both where 1 min of vigorous activity counts approximately the same as 2 min of moderate intensity activity. This implies that when the overall activity energy expenditure is held constant, moderate and vigorous intensity activities produce similar health benefits. However, activities of at least vigorous intensities are required to improve or maintain cardiorespiratory fitness in healthy populations,[8–13] which is considered a powerful predictor of clinical outcomes[14] and mortality.[15–19]

To date, few epidemiological studies have examined the association between the intensity of physical activity and mortality while controlling for the volume of activity, yielding mixed results.[20–24] While some prospective studies found a lower risk in all-cause[20 23 24] and cardiovascular disease (CVD) mortality[21] in participants reporting larger proportions of vigorous intensity, another study found inconsistent associations with CVD mortality in both sexes and a reduction in all-cause mortality only in men.[22] Regarding the influence of physical activity on cancer, a recent meta-analysis[25] observed an inverse association between the volume of physical activity and the risk of cancer mortality.

To our knowledge, no previous epidemiological studies have examined the role of vigorous activity (vs moderate and holding constant total physical activity) in cancer mortality.

Using data from a series of large British cohorts, we examined whether the proportion of total physical activity accrued by vigorous activities was associated with all-cause, CVD and total cancer mortality independent of the total amount of activity.

METHODS

Population

The Health Survey for England (HSE) and the Scottish Health Survey (SHeS) are household-based prospective studies in which households were selected using a multistage, stratified probability design to achieve representative samples of the population of England and Scotland. Stratification was based on geographical characteristics (postcode sectors were selected at the first stage). Local research ethics committees approved the data collection of each survey. The present study included 11 population cohorts of individuals aged 30 years or older: HSE 1994, 1997, 1998, 1999, 2003, 2004, 2006 and 2008; SHeS 1995, 1998 and 2003.[26,27] For this study, we excluded all individuals that reported no moderate-to-vigorous physical activity (MVPA) and/or did not provide information for any of the covariates included in the statistical models.

Measurement of exposure

Physical activity was measured by an interviewer-administered questionnaire as described elsewhere.[28,29] Participants were asked about the frequency, duration and pace of walking (slow, average or brisk) and domestic physical activity. In addition, data on physical activity in sports and exercise were collected (frequency, duration and perceived intensity over the last 4 weeks) using a prompt card. This contained 10 main groupings, including cycling, swimming, running, football, rugby, tennis and squash. Up to six open entries could be recorded. Perceived moderate intensity activities correspond to a slight increase in the heart rate (3.0–5.9 METs), whereas vigorous activities get people out of breath and make them sweat (6.0 or more METs, where 1 MET represents the resting energy expenditure).[4] The criterion validity of the physical activity questionnaire used in the HSE has been described previously.[29]

Measurement of the outcomes

The British National Health Service Central Registry flagged all participants. Primary cause of death was determined based on the codes from the International Classification of Diseases, Ninth Revision (ICD-9) and the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10). CVD mortality codes were 390 to 459 for ICD-9 and I01 to I99 for ICD-10, and for cancer mortality were 140 to 239 for ICD-9 and C00 to D48 for ICD-10.

Covariates

Height and weight were measured objectively by trained interviewers following standard protocols.[26,27] Body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared. Then, we categorised participants as normal weight (BMI <25) and overweight/obese (BMI ≥25). Education level was assessed as the age at which each participant finished full-time education (recoded into ≤15, 15–18 and ≥19 years old). For alcohol consumption, researchers asked the frequency of drinking during the last week (recoded into <5 or ≥5 times/week). Smoking status was categorised as never or ex-regular or ex-occasional or current smoker. Longstanding illness was defined when individuals had at least one illness within a list of illnesses affecting different body systems (ie, the nervous system, heart and circulatory system). Cancer or CVD (angina, stroke and coronary heart disease) diagnosis was based on medical reports. The General Health Questionnaire (GHQ-12) was used to assess psychological distress which is considered a valid tool.[30]

Statistical analysis

Cox proportional hazards regression models were used to estimate the association between the proportion of total weighted MVPA as vigorous activity and all-cause, CVD and cancer mortality. We examined the proportional hazards assumption and, as statistical tests were violated (χ^2=28.43, p=0.0002), we alternatively used stratified Cox proportional regression models. By doing so, no violations were noted (χ^2=4.35, p=0.23). Cox models were stratified by age, sex, education and smoking and adjusted for alcohol consumption, total weighted volume of MVPA and longstanding illness. For the outcome CVD mortality, models were additionally adjusted for CVD diagnosis at baseline. For cancer mortality, models were additionally adjusted for cancer diagnosis at baseline. To account for potential reverse causation through occult disease at baseline, analyses were repeated excluding those subjects who died during the first 24 months of follow-up. We created the variable ‘proportion of weighted MVPA by vigorous activity’ (three levels) based on the cut-points used in two previous publications[23,24]: (1) 0%; (2)>0% to <30%; and (3) ≥30% of MVPA by vigorous activity.

Sensitivity analyses were also performed to account for additional confounders. Model 1 was additionally adjusted for BMI. Model 2 included model 1 plus psychological distress. Because of the relatively small size of the >0% to <30% of MVPA by vigorous physical activity group, we also regrouped the exposure variable using a distribution-driven approach to elicit more equal groups: 0% of vigorous; > 0 to <60% of physical activity as vigorous: >60% of MVPA as vigorous (online supplementary table 2). Finally, we explored associations comparing the highest intensity level achieved by participants versus moderate intensity (online supplementary table 3). All analyses were performed with the statistical package STATA V.14 (StataCorp, College Station, Texas, USA).

RESULTS

Descriptive characteristics of the sample are shown in table 1. Of the 64913 adult respondents, 56% were women, 59.5% were overweight or obese, 75.8% were non-current smokers, 80% did not drink alcohol frequently (less than five times per week) and 84.7% did not report psychological distress. More than half (58.3%) of the participants met the WHO's physical activity recommendations[7] of 150 min of weighted MVPA per week. Of those who engaged in any MVPA, 68.6% did not report any vigorous activity, 7.7% reported less than 30% and 23.7% reported 30% or more of their total MVPA as vigorous activity. The highest total volume of physical activity was in the 0%–30% vigorous group, who reported a median of 461 min per week of MVPA. Participants who were younger, male and sufficiently active were more likely to engage in some vigorous activity. The main analyses included 64913 (all-cause mortality), 57702 (CVD mortality) and 63677 (cancer mortality) participants.

All-cause mortality

Table 2 presents the associations between the proportion of MVPA weighted by vigorous activity and all-cause mortality. Of the 64913 participants, 5064 deaths were registered during 435743 person-years of follow-up (mean (SD) follow-up, 9.0 (93.6) years). In the whole sample, compared with those not engaging in any vigorous activity (0%), the adjusted HR for all-cause mortality was as follows: HR=0.84 (95% CI 0.71, 0.99) for participants reporting between >0 and <30% of MVPA as vigorous; and HR=0.84 (95% CI 0.76, 0.94) for those reporting ≥30% of MVPA as vigorous. In men, the adjusted HR=0.88 (95% CI 0.71, 1.10) in the group >0 to<30%, and HR=0.81 (95% CI 0.70, 0.93) in the group ≥30% of MVPA as vigorous activity. In women, HR=0.77 (95% CI 0.58, 1.01) and HR=0.90 (95% CI 0.77, 1.05), respectively. The beneficial associations observed with vigorous activity were attenuated with age. For example, for those who reported 30% or more of MVPA as vigorous activity, the adjusted HR for all-cause mortality was 0.73 (95% CI 0.59, 0.91) in participants aged 30–49 years old versus HR=0.93 (95% CI 0.79 to 1.10) in participants aged ≥65 years. Regardless of whether individuals met physical activity guidelines or not, vigorous physical activity showed protective effects on all-cause mortality risk. For example, we found a 15% risk reduction (HR=0.85, 95% CI 0.74, 0.98) in participants who achieved the recommended 150 min of MVPA and reported 30% or more of vigorous activity; and a 12% non-statistically significant reduction (HR=0.88, 95% CI 0.74, 1.05) in those that did not meet the physical activity guidelines.

CVD mortality

Table 3 shows point estimates and CIs between the proportion of MVPA as vigorous activity and CVD-mortality risk. In the whole sample, the adjusted HRs were HR=0.83 (95% CI 0.57 to 1.18) and HR=0.84 (95% CI 0.68 1.04) for participants reporting >0% to <30% and ≥30%, respectively. However, estimates were imprecise as indicated by their wide CIs (eg, in women HR=0.61 (95% CI 0.30, 1.25) in the category group >0% to <30% of MVPA by vigorous activity). In analyses stratified by age, there was weak evidence for associations, despite in the youngest group with ≥30% of MVPA as vigorous, the risk of CVD was 41% lower (95% CI 0.36 to 0.97). Stratifying participants by adherence to the physical activity recommendations showed no evidence of association in most subgroups, with the only exception of meeting activity guidelines and ≥30% of their MVPA as vigorous (HR=0.71, 95% CI 0.53, 0.97).

Cancer mortality

Table 4 shows results of the analyses with cancer mortality as the outcome. In the whole sample, there was weak evidence of vigorous activity being associated with lower cancer mortality risk: HR=0.79 (95% CI 0.60, 1.06) and HR=0.89 (95% CI 0.75, 1.06) for participants reporting >0% to <30% and ≥30% of MVPA as vigorous, respectively. However, in most subgroup analyses estimates were less consistent and pointed towards no association. In analyses stratified by sex, there was evidence of a beneficial association of a high proportion of vigorous activity with cancer mortality risk HR=0.83 (95% CI 0.65, 1.05) only in men. In analyses stratified by age, we found evidence of an association with cancer mortality only among participants aged 50–65 years: HR=0.66 (95% CI 0.43, 1.04) and HR=0.77 (95% CI 0.60, 1.00) for >0% to <30% and ≥30%, respectively.

Sensitivity analyses

Online supplementary table 1 includes the same statistical models of survival analyses previously used but adjusted for other covariates. Model 1 was additionally adjusted for BMI. Model 2 included model 1 plus psychological distress. Results did not change the pattern of the findings shown in tables 2–4.

When using an alternative categorisation of the proportion of MVPA as vigorous (0%,>0 to <60%, ≥60%) (online supplementary table 2), which was more balanced in terms of group sample size, we found that only low to moderate proportions of vigorous activity (>0 to <60%) were associated with lower mortality risk (for all causes, CVD and cancer). Similarly, when we explored another simple indicator of intensity (highest PA intensity achieved), vigorous intensity was again associated with lower mortality risk (online supplementary table 3).

DISCUSSION

Principal findings

Using pooled data from 11 cohorts from England and Scotland, we examined the association between different relative proportions of vigorous physical activity and

Table 1 Characteristics of participants at baseline (n=64 913) in the Health Survey for England and Scottish Health Survey

Number (%) of participants

Variable	Proportion of moderate to vigorous activity classified as vigorous: 0%	>0% to <30%	≥30%	Total participants, n
Total sample, n (%)	44 521 (68.6)	5000 (7.7)	15 392 (23.7)	64 913
Sex, n (%)				
Male	18 421 (64.5)	2341 (8.2)	7805 (27.3)	28 567
Female	26 100 (71.8)	2659 (7.3)	7587 (20.9)	36 346
Age group, y				
30–49	20 363 (58.3)	3521 (10.1)	11 024 (31.6)	34 908
50–64	14 441 (75.8)	1202 (6.3)	3413 (17.9)	19 056
65-max	9717 (88.7)	277 (2.5)	955 (8.7)	10 949
Age finished full-time education, n (%)				
≤15 y	18 216 (82.8)	1042 (4.7)	2745 (12.5)	22 003
16–18 y	19 329 (64.8)	2617 (8.8)	7876 (26.4)	29 822
≥19 y	6976 (53.3)	1341 (10.2)	4771 (36.5)	13 088
Smoking status, n (%)				
Non-current	32 508 (66.1)	3930 (8.0)	12 736 (25.9)	49 174
Current	12 013 (76.3)	1070 (6.8)	2656 (16.9)	15 739
Alcohol consumption frequency, n (%)				
<5 times/week	35 979 (68.8)	3953 (7.6)	12 317 (23.6)	52 249
≥5 times/week	8542 (67.4)	1047 (8.3)	3075 (24.3)	12 664
Long-standing illness, n (%)				
No	24 071 (64.8)	3178 (8.5)	9906 (26.7)	37 155
Yes	20 450 (73.7)	1822 (6.5)	5486 (19.8)	27 758
Weighted MVPA, min/week				
10–149	23 126 (85.7)	485 (1.8)	3380 (12.5)	26 991
≥150	21 362 (56.5)	4496 (11.9)	11 960 (31.6)	37 818
Median physical activity levels (IQRs)	195 (80–442.5)	137.5 (60–322.5)	461.4 (255–817)	329 (165–615)
BMI, n (%)				
<25 (normal weight)	17 941 (67.1)	2189 (8.2)	6603 (24.7)	26 733
≥25 (overweight/obesity)	26 902 (69.6)	2843 (7.4)	8880 (23.0)	38 625
BMI, mean (SD)	24.86 (9.18)	24.53 (8.34)	24.60 (8.64)	24.78 (8.99)
Psychological distress, n (%)				
No: GHQ score <4	37 450 (68.1)	4273 (7.8)	13 253 (24.1)	54 976
Yes: GHQ score ≥4	5718 (70.4)	623 (7.7)	1781 (21.9)	8122

Smoking status was based on one question with the following options: never, ex-regular smoker, ex-occasional smoker, current smoker. Alcohol use was derived from the question “On how many days in the last 7 days did you have an alcoholic drink?”. Long standing illness included at least one illness from a list of body systems (ie, nervous system, heart and circulatory system). The definition of psychological distress was based on the General Health Questionnaire (GQH) comprising 12 questions related with psychological health.
BMI, body mass index; MVPA, moderate-to-vigorous physical activity; max, maximal; y, years.

all-cause, CVD and cancer mortality risk. Our overall findings support the hypothesis that activities of vigorous activity may provide additional reductions in mortality risk (ie, 16% risk reduction for all-cause mortality), in line with results obtained elsewhere,[23 24] yet for cause-specific mortality (CVD, cancer) uncertainty arose as point estimates were wider and crossed the unity.

In contrast to a previous study,[23] we did not find evidence of a dose–response reduction in mortality risk with a larger proportion of vigorous activity, which is in

Table 2 Stratified Cox regression (by age, sex, education and smoking) describing associations between vigorous activity and all-cause mortality

		Proportion of moderate to vigorous activity classified as vigorous					
		0%		>0% to <30%		≥30%	
Variable	Total No. of Participants/Events	N/Events	Reference	N/Events	HR (95% CI)	N/Events	HR (95% CI)
All sample	64913/5064	44521/4477	1	5000/151	0.84 (0.71 to 0.99) p=0.04	15392/436	0.84 (0.76 to 0.94) p=0.002
All sample (excluding first 24 months of death)	64186/4507	43924/3986	1	4972/135	0.84 (0.70 to 1.01) p=0.05	15290/386	0.85 (0.76 to 0.95) p=0.005
Sex							
Men	28567/2630	18421/2296	1	2341/94	0.88 (0.71 to 1.10) p=0.28	7805/240	0.81 (0.70 to 0.93) p=0.003
Women	36346/2434	26100/2181	1	2659/57	0.77 (0.58 to 1.01) p=0.06	7587/196	0.90 (0.77 to 1.05) p=0.19
Age group, y							
30–49	34908/606	20363/431	1	3521/58	0.95 (0.71 to 1.27) p=0.74	11024/117	0.73 (0.59 to 0.91) p=0.006
50–64	19056/1388	14441/1181	1	1202/51	0.74 (0.55 to 0.98) p=0.04	3413/156	0.84 (0.71 to 1.01) p=0.05
≥65	10949/3070	9717/2865	1	277/42	0.81 (0.59 to 1.11) p=0.20	955/163	0.93 (0.79 to 1.10) p=0.38
Weighted MVPA, min/week							
10–149	26991/2888	23126/2719	1	485/18	0.91 (0.56 to 1.48) p=0.71	3380/151	0.88 (0.74 to 1.05) p=0.147
>150	37895/2149	21395/1758	1	4515/133	0.87 (0.72 to 1.04) p=0.132	11985/258	0.85 (0.74 to 0.98) p=0.02

For all sample values were adjusted for alcohol consumption, total weighted volume of moderate-to-vigorous physical activity (MVPA) and longstanding illness.
N, total population; No, number.

line with other studies.[22 24] It must be noted, however, that the benefits of vigorous activity in all-cause mortality risk were restricted to young and middle-aged participants, unlike a previous study where the benefits were independent of the age of participants.[23] The null association observed in older adults in the present study could be due to their low physical activity levels. For example, in the study of Gebel *et al*,[23] 61% of participants aged 65–75 years reported no vigorous activity vs 89% in the current study (see table 1).

For CVD mortality (table 2), we found weak evidence linking vigorous activity with additional reductions in mortality risk. The protective CVD effect of vigorous intensity was only observed in men in agreement with data found in Shiroma *et al*.[22] We noted that the benefits were mainly accrued to 'any vigorous activity' (the 0%–30% vigorous activity group). The categorisation of the exposure variable was directly comparable to studies published in Australia[23] and Japan,[24] but this posed some analytical challenges as there was a relatively small number of participants in the middle group category (>0% to <30% of MVPA by vigorous activity). In sensitivity analysis where an alternative categorisation of the VPA exposure variable was used to elicit exactly balanced sample sizes between groups (online supplementary table 2), we found evidence of beneficial associations for the middle category (>0 to <60% of MVPA by vigorous activity) on all-cause and cancer mortality, but with the highest doses of vigorous activity (≥60% of MVPA), the protective associations found with all outcomes were not statistically significant. The hypothesis that an excessive amount of exercise at high intensity could adversely affect cardiac function and increase CVD mortality risk is a topic of debate,[31] but this hypothesis is not supported by the results of our observational study.

Regarding cancer mortality, we found inconsistent results (evidence of a protective association with the whole sample, but weak evidence across subgroup analyses). These uncertainties seem concordant with the limited evidence of the preventive role of physical activity on many cancer sites.[32] Another limitation in our analysis is that all cancer deaths were pooled into one outcome variable. Future studies about this topic should explore associations between intensities of physical activity and incidence and mortality of cancer-specific sites.

Table 3 Stratified Cox regression (by age, sex, education and smoking) describing associations between vigorous activity and cardiovascular (CVD) mortality

Proportion of moderate to vigorous activity classified as vigorous							
		0%		>0% to <30%		≥30%	
Variable	Total No. of Participants/Events	N/Events	Reference	N/Events	HR (95% CI)	N/Events	HR (95% CI)
All sample	57 702/1393	39 913/1252	1	4316/35	0.83 (0.57 to 1.18) p=0.31	13 473/106	0.84 (0.68 to 1.04) p=0.11
All sample (excluding first 24 months of death)	57 119/1270	39408/1142	1	4296/32	0.83 (0.57 to 1.20) p=0.32	13 415/96	0.84 (0.67 to 1.05) p=0.126
Sex							
Men	25 381/766	16 528/676	1	2023/27	0.94 (0.63 to 1.41) p=0.76	6830/63	0.78 (0.60 to 1.03) p=0.08
Women	32 321/627	23 385/576	1	2293/8	0.61 (0.30 to 1.25) p=0.18	6643/43	0.94 (0.68 to 1.31) p=0.72
Age group, y							
30–49	30 760/124	18 126/92	1	047/10	0.71 (0.36 to 1.39) p=0.31	9587/22	0.59 (0.36 to 0.97) p=0.04
50–64	17 209/311	13 141/263	1	1037/9	0.63 (0.32 to 1.23) p=0.17	3031/39	0.96 (0.68 to 1.36) p=0.84
≥65	9733/958	8646/897	1	232/16	0.79 (0.48 to 1.30) p=0.35	855/45	0.65 (0.48 to 0.88) p=0.005
Weighted MVPA, min/week							
10–149	24 500/850	20 999/795	1	439/4	0.82 (0.29 to 2.27) p=0.70	3062/51	1.05 (0.77 to 1.43) p=0.75
>150	33 202/543	18 914/457	1	3877/31	0.84 (0.57 to 1.25) p=0.39	10 411/55	0.71 (0.53 to 0.97) p=0.03

For all sample values were adjusted for alcohol consumption, total weighted volume of moderate-to-vigorous physical activity (MVPA), longstanding illness and CVD diagnosis at baseline.
N, total population; No, number.

Strengths and limitations of the study

Our study included cause-specific death records from a series of large, nationally representative cohorts. In large cohort studies,[23] physical activity data are commonly collected by questionnaires which may lead to recall biases.[33 34] However, vigorous activity is considered a more accurate reported variable compared with activities of lower intensity.[34–36] To minimise the risk that our findings could be explained by reverse causation, the reference category in our analyses included those with some moderate physical activity (but no vigorous activity) based on a previous study.[23] A recent study from Japan[24] included the two different comparator groups (physically inactive and moderate intensity active groups), and larger effect sizes were observed using the inactive group as reference. Nonetheless, given the limitations inherent in any observational study, we cannot totally discard that our associations may have been biased. A lack of adjustment for unknown confounders (ie, dietary factors, undetected comorbidities) may challenge the internal validity of our findings. We also excluded all deaths during the first 2 years of follow-up and the results remained broadly the same. However, future epidemiological studies should employ more strict criteria to control for reverse causation (ie, excluding participants after the first 4 or 6 years of follow-up).

Public health implications

Although the first public health goal is to meet physical activity guidelines (regardless of the intensity achieved), our data indicate that a single estimate of vigorous activity in adulthood is associated with lower mortality risk compared with activities of moderate intensity. Finally, our stratified analysis also supports the importance of accumulating a minimal amount of activity for health purposes because in participants who achieved less than 150 weekly minutes of MVPA, vigorous activity was not associated with lower mortality.

We conclude that holding constant the amount of physical activity, vigorous activity may confer larger reductions in mortality risk than activities of moderate intensity.

Patient and public involvement

Patients were not involved in the design, recruitment, or execution of this study.

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Table 4 Stratified Cox regression (by age, sex, education and smoking) describing associations between vigorous activity and cancer mortality

Proportion of moderate to vigorous activity classified as vigorous							
		0%		>0% to<30%		≥30%	
Variable	Total No. of Participants/Events	N/Events	Reference	N/Events	HR (95% CI)	N/Events	HR (95% CI)
All sample	63 677/1602	43 576/1384	1	4936/53	0.79 (0.60 to 1.06) p=0.12	15 165/165	0.89 (0.75 to 1.06) p=0.20
All sample (excluding first 24 months of death)	63 018/1447	43 039/1247	1	4912/51	0.83 (0.62 to 1.11) p=0.21	15 067/149	0.89 (0.74 to 1.06) p=0.20
Sex							
Men	28111/805	18 068/692	1	2315/29	0.83 (0.56 to 1.22) p=0.34	7728/84	0.83 (0.65 to 1.05) p=0.13
Women	35 566/797	25 508/692	1	2621/24	0.78 (0.51 to 1.19) p=0.25	7437/81	0.98 (0.77 to 1.25) p=0.86
Age group, y							
30–49	34 593/218	20 166/154	1	3491/21	0.96 (0.60 to 1.55) p=0.87	10 936/43	0.78 (0.54 to 1.11) p=0.17
50–64	18 593/612	14 093/523	1	1180/21	0.66 (0.43 to 1.04) p=0.07	3320/68	0.77 (0.60 to 1.00) p=0.05
≥65	10 491/772	9317/707	1	265/11	0.65 (0.36 to 1.19) p=0.16	909/54	0.97 (0.74 to 1.29) p=0.86
Weighted MVPA, min/week							
10–149	26 991/2888	23 126/2719	1	485/18	0.67 (0.27 to 1.67) p=0.39	3380/151	0.90 (0.66 to 1.21) p=0.47
>150	37 895/2149	21 95/1758	1	4515/133	0.85 (0.62 to 1.15) p=0.30	11 985/258	0.93 (0.75 to 1.16) p=0.54

For all sample values adjusted for alcohol consumption, total weighted volume of moderate-to-vigorous physical activity (MVPA), longstanding illness and baseline cancer diagnosis at baseline.
N, total population; No, number.

Contributors ES conceived and designed the study. JPRL conducted the literature search, performed the statistical analyses and wrote the first draft of the paper. All authors interpreted the data, and contributed to the draft of the paper, revised the subsequent drafts, and read and approved the final manuscript. JPRL takes primary responsibility for the accuracy of the data analysis.

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REFERENCES

1. Bouchard C, Blair SN, Haskell WL. *Physical activity and health*. 2 ed. Champaign: Human Kinetics, 2012.
2. World Health Organization. *Global health risks: mortality and burden of disease attributable to selected major risks*. Geneva: World Health Organization, 2009.
3. Lee I-M, Shiroma EJ, Lobelo F, *et al*. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380:219–29.
4. Physical activity guidelines Advisory Committee. 2018 physical activity guidelines Advisory Committee scientific report. Washington, DC U.S. Department of Health and Human Services; 2018.
5. Bull FC, Groups EW. *Physical activity guidelines in the U.K.: review and recommendations*. School of Sport, Exercise and Health Sciences, Loughborough University: Loughborough, 2010.
6. Department of Health. *Australia's physical activity and sedentary behaviour guidelines*. Canberra: Department of Health, 2014.
7. World Health Organization. *Global recommendations on physical activity for health*. Geneva: World Health Organization, 2010.
8. Lee IM, Paffenbarger JRS. Is vigorous physical activity necessary to reduce the risk of cardiovascular disease? In: Leon AS, ed. *Physical activity and cardiovascular health*. Champaign: Human Kinetics, 1997: 67–75.
9. Swain DP, Franklin BA. VO(2) reserve and the minimal intensity for improving cardiorespiratory fitness. *Med Sci Sports Exerc* 2002;34:152–7.
10. Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol* 2006;97:141–7.
11. Wisløff U, Støylen A, Loennechen JP, *et al*. Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients: a randomized study. *Circulation* 2007;115:3086–94.
12. Nokes N. Relationship between physical activity and aerobic fitness. *J Sports Med Phys Fitness* 2009;49:136–41.

13. Drenowatz C, Prasad VK, Hand GA, *et al*. Effects of moderate and vigorous physical activity on fitness and body composition. *J Behav Med* 2016;39:624–32.
14. Kaminsky LA, Arena R, Beckie TM, *et al*. The importance of cardiorespiratory fitness in the United States: the need for a national registry: a policy statement from the American heart association. *Circulation* 2013;127:652–62.
15. Piercy KL, Troiano RP, Ballard RM, *et al*. The physical activity guidelines for Americans. *JAMA* 2018;320:2020–8.
16. Sassen B, Cornelissen VA, Kiers H, *et al*. Physical fitness matters more than physical activity in controlling cardiovascular disease risk factors. *Eur J Cardiovasc Prev Rehabil* 2009;16:677–83.
17. Williams PT. Physical fitness and activity as separate heart disease risk factors: a meta-analysis. *Med Sci Sports Exerc* 2001;33:754–61.
18. Myers J, Kaykha A, George S, *et al*. Fitness versus physical activity patterns in predicting mortality in men. *Am J Med* 2004;117:912–8.
19. Stamatakis E, Hamer M, O'Donovan G, *et al*. A non-exercise testing method for estimating cardiorespiratory fitness: associations with all-cause and cardiovascular mortality in a pooled analysis of eight population-based cohorts. *Eur Heart J* 2013;34:750–8.
20. Lee IM, Paffenbarger RS, light Aof. Associations of light, moderate, and vigorous intensity physical activity with longevity. The Harvard alumni health study. *Am J Epidemiol* 2000;151:293–9.
21. Tanasescu M, Leitzmann MF, Rimm EB, *et al*. Exercise type and intensity in relation to coronary heart disease in men. *JAMA* 2002;288:1994–2000.
22. Shiroma EJ, Sesso HD, Moorthy MV, *et al*. Do moderate-intensity and vigorous-intensity physical activities reduce mortality rates to the same extent? *J Am Heart Assoc* 2014;3:e000802.
23. Gebel K, Ding D, Chey T, *et al*. Effect of moderate to vigorous physical activity on all-cause mortality in middle-aged and older Australians. *JAMA Intern Med* 2015;175:970–7.
24. Kikuchi H, Inoue S, Lee I-M, *et al*. Impact of moderate-intensity and Vigorous-Intensity physical activity on mortality. *Med Sci Sports Exerc* 2018;50:715–21.
25. Li Y, Gu M, Jing F, *et al*. Association between physical activity and all cancer mortality: dose-response meta-analysis of cohort studies. *Int J Cancer* 2016;138:818–32.
26. Mindell J, Biddulph JP, Hirani V, *et al*. Cohort profile: the health survey for England. *Int J Epidemiol* 2012;41:1585–93.
27. Gray L, Batty GD, Craig P, *et al*. Cohort profile: the Scottish health surveys cohort: linkage of study participants to routinely collected records for mortality, hospital discharge, cancer and offspring birth characteristics in three nationwide studies. *Int J Epidemiol* 2010;39:345–50.
28. Stamatakis E, Ekelund U, Wareham NJ. Temporal trends in physical activity in England: the health survey for England 1991 to 2004. *Prev Med* 2007;45:416–23.
29. Scholes S, Coombs N, Pedisic Z, *et al*. Age- and sex-specific criterion validity of the health survey for England physical activity and sedentary behavior assessment questionnaire as compared with accelerometry. *Am J Epidemiol* 2014;179:1493–502.
30. Goldberg DP, Gater R, Sartorius N, *et al*. The validity of two versions of the GHQ in the WHO study of mental illness in general health care. *Psychol Med* 1997;27:191–7.
31. Eijsvogels TMH, Fernandez AB, Thompson PD. Are there deleterious cardiac effects of acute and chronic endurance exercise? *Physiol Rev* 2016;96:99–125.
32. Rezende LFMde, Sá THde, Markozannes G, *et al*. Physical activity and cancer: an umbrella review of the literature including 22 major anatomical sites and 770 000 cancer cases. *Br J Sports Med* 2018;52:826–33.
33. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport* 2000;71(sup2):1–14.
34. Sattelmair J, Pertman J, Ding EL, *et al*. Dose response between physical activity and risk of coronary heart disease: a meta-analysis. *Circulation* 2011;124:789–95.
35. Craig CL, Marshall AL, Sjöström M, *et al*. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 2003;35:1381–95.
36. Dyrstad SM, Hansen BH, Holme IM, *et al*. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc* 2014;46:99–106.