COVER PAGE

Title: Does strength promoting exercise confer unique health benefits? A pooled analysis of eleven population cohorts with all-cause, cancer, and cardiovascular mortality endpoints.

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FOOTNOTES

BMI	Body mass index
CI	Confidence intervals
CVD	Cardiovascular disease
HSE	Health Survey for England
ICD	International Classification of Diseases
ICD9	International Classification of Diseases, Ninth Revision
ICD10	International Classification of Diseases, Tenth Revision
MET	Metabolic Equivalents
NHMRC	National Health and Medical Research Council (Australia)
NIHR	National Institute for Health Research (UK)
PRT	Progressive resistance training
SHS	Scottish Health Survey
SPE	Strength-promoting exercise

ABSTRACT

Public health guidance includes strength-promoting exercise (SPE) but there is little evidence on its links with mortality. Using data from 11 cohorts we examined the associations between SPE (gym-based and own bodyweight strength activities) and all-cause, cancer, and cardiovascular disease (CVD) mortality. Multivariable-adjusted Cox regression examine the associations between SPE (any, low/high volume, adherence to SPE guideline) and mortality. The core sample comprised 80,306 adults aged ≥30 years corresponding to 5,763 any cause deaths (681,790 person years). Following exclusions for prevalent disease/events in the first 24 months, participation in any SPE was favorably associated with all cause (0.77, 95% confidence interval: 0.69 to 0.87) and cancer mortality (0.69, 0.56 to 0.86). Adhering only to the SPE guideline of (≥2 sessions/week) was associated with cancer (0.66, 0.48 to 0.92) and all-cause (0.79, 0.66 to 0.94) mortality; adhering only to the aerobic guideline (150 minutes/week of moderate or 75 minutes/week of vigorous intensity or equivalent combinations) was associated with all-cause (0.84, 0.78 to 0.90) and CVD (0.78, 0.68 to 0.90) mortality. Adherence to both guidelines was associated with all-cause (0.71, 0.57 to 0.87), and cancer (0.70, 0.50 to 0.98) mortality. Our results support promoting adherence to the strength exercise guidelines over and above the generic physical activity targets.

Keywords: cancer, cardiometabolic, cardiovascular, epidemiology, mortality, physical activity, resistance training, strength promoting exercise, strength training

INTRODUCTION

Regular physical activity participation has a well-established association with reductions in all-cause, cardiovascular, diabetes and cancer-related mortality (1, 2). In the last decade, strength promoting exercise (SPE) has become an integral component of physical activity guidelines around the world (3, 4) with the World Health Organization recommending at least two sessions per week.

Current SPE guidelines are primarily intended to increase strength and function and there are few data on associations with chronic disease and mortality. Participation in strength exercise has been associated with reduced risk of type II diabetes in men (40-75 years) (5), women (36-81 years) (6) and working age populations (30-64 years) (7). These associations were independent of aerobic exercise, conferred greater benefit when combined with aerobic exercise (5, 6), and were more pronounced in older adults (7). Compared to aerobic forms of physical activity, SPE is unique in its ability to promote increases in muscle size and strength, with higher muscle mass (8, 9) and strength (10) previously associated with a lower mortality risk. Thus, SPE may be promising for reducing premature mortality and chronic disease risk.

However, few studies have explored associations between strength promoting exercise and cause-specific mortality. SPE has been shown to be associated with reduced risk fatal and non-fatal myocardial infarction among adult men (11) and all-cause mortality in cancer survivors (12), and recent studies have shown also shown reductions in all-cause mortality amongst adults who meet the guidelines of two sessions per week (13-15). However, limited conclusions can be drawn, with the few published studies limited to usually older adults residing in the US (13) and small cohorts (12, 14, 15) with no measures taken to account reverse causality by removing prevalent cases (13-15) or excluding events at the first few months of years of follow-up (11, 13-15).

The aim of this study was to examine the associations between SPE and all-cause, cardiovascular and cancer mortality; and to compare the SPE and aerobic activity guidelines in terms of their associations with mortality outcomes.

METHODS

Sample

The Health Survey for England (HSE) (16) and the Scottish Health Survey (SHS) (17) are established household-based population surveillance studies running since 1991 and 1995, respectively. Each year samples are selected using a multistage, stratified probability design aimed at recruiting a nationally representative sample. Trained interviewers visited the selected households, and the recruited participants were administered the study questionnaires. All survey participants gave written consent to have their death flagged on the NHS Central Mortality Register. This study includes individuals aged ≥30 years old from HSE 1994, 1997, 1998, 1999, 2003, 2004, 2006 and 2008 and SHS 1995, 1998 and 2003, with the corresponding linkage to mortality data. Each baseline survey was approved by the relevant Research Ethics Committees in England and Scotland.

Mortality outcomes

Participants were followed up for mortality until 31/12/2009 (SHS) or 31/03/2011 (HSE). Diagnoses for primary causes of death were recorded according to the International Classification of Diseases, Ninth Revision (ICD9) and Tenth Revision (ICD10). Cancer deaths were identified using ICD9 140.0-239.9 and ICD10 C00.0-D48.9 codes; CVD deaths were identified using ICD9 390.0-459.9 and ICD10 I01.0-I99 codes.

Assessment of strength-promoting exercise and other physical activity

Physical activity was assessed using a questionnaire (18) that inquired about participation in sports and exercises in the four weeks prior to the interview. Participants were shown a card (see supplement, Illustration e1) with 10 exercise groupings including workout at a gym/weight training/exercise bike that we labelled "gym-based" SPE and exercises such as press-ups and sit ups that we labelled "own bodyweight" SPE. For each positive response participants were asked if they had participated for at least 15 minutes, the frequency (number of occasions), and duration per occasion. "All strength exercise" (total SPE) was defined as the sum of gym –based and own bodyweight SPE. The questionnaire also included items on domestic physical activity (19) and walking (20) that have been described in detail elsewhere (19, 20). All physical activity variables were summarized to reflect weekly averages. In a large validation study, the Spearman correlation coefficients between accelerometry counts and self-reported activity converted to weekly MET-minutes was 0.41 (95% confidence interval (CI): 0.36, 0.46) for women and 0.32 (CI: 0.26, 0.38) for men (18).

To minimize misclassification arising from likely inclusion of aerobic exercise, the volume of the gym-based workout was weighted using age and sex-specific proportions of total gym-based activity that was reported to be "strength work out at a gym using machines or free weights derived using the pooled samples of the 2008 (21) (n=12,360) and 2012 (22) (n=6,883) that included additional questions specifying the nature of the gym-based activity (Table e1). On average, 63% of the gym-based activity in those two years was SPE, with a tendency for a decrease by age group from 86% in those aged 30-35 to 61% among those 75 years or older. The physical activity compendium (23) was used to assign the Metabolic Equivalents (MET) for all physical activity to calculate total MET-hours/week. Like previously (24) we estimated adherence to the aerobic guideline as 150 minutes/week of moderate intensity or 75 minutes/week of vigorous intensity or equivalent combinations of moderate and vigorous non-SPE / non-domestic physical activity (4). We also computed an alternative interpretation of the aerobic guideline defined as accumulating at least 7.5 MET-hours/week (25) of any type and intensity (26) non-SPE physical activity . Adherence to the SPE gudeline was defined as reporting partticipation in at least two sessions per week on average.

Covariates

Height and weight were measured by the interviewers using standard protocols (16, 17); body mass index (BMI) was calculated as weight (in kilograms) divided by height (in meters) squared. Additional questions assessed age, educational attainment (age completed full time education), presence of longstanding illness, weekly frequency of alcohol consumption, smoking habits (never smoker, ex-smoker, currently smoking 1-10 cigarettes/day, currently smoking 10-19/day, currently smoking $\geqslant$20/day), psychological distress/depression (12-point General Health Questionnaire score), and number of fruit and vegetable servings consumed the day prior to the interview.

Statistical analysis

Analyses were carried out using SPSS version 22 (SPSS, Inc). Cox proportional-hazard models were used to examine the associations between total and type-specific SPE and all-cause, cancer, and CVD mortality with “no participation” set as the reference category. Log-minus-log plots were used to examine the proportional-hazards assumption and no violations were observed. Analyses were adjusted for age, sex, all covariates listed above, and weekly MET-hours of non-SPE activity. We examined associations between overall participation (none/any) and volume (none/low/high) with mortality outcomes. High and low weekly volumes were classified using the sex-specific medians of the corresponding variable (Table e1). We examined the association between meeting the strength promoting guideline (≥ 2 sessions/week)(4) and mortality; and compared associations with meeting the general (aerobic) one using a 4-level variable: meeting neither of the two recommendations (referent), meeting the SPE recommendation only, meeting aerobic recommendation only, and meeting both recommendations. To minimize the possibility of spurious associations due to occult disease we excluded participants who died in the first 24 months of follow-up. We excluded those with prevalent cancer at baseline from the cancer mortality analyses; those with prevalent CVD (angina/stroke/ischemic heart disease) from the CVD mortality analyses; and both prevalent CVD and cancer from the all-cause mortality analyses. Unless otherwise stated in the results, the own bodyweight and gym-based SPE were not mutually exclusive.

We performed a series of sensitivity analyses to minimize bias and enable a more robust interpretation of the results:

- We examined the role of dietary confounding by repeating all main Cox analyses with additional adjustment for fruit and vegetable consumption (27) in a sub-sample.

- To minimize the possibility that the associations between SPE and mortality are not due to the aerobic exercise element included in the gym-based SPE question, we repeated various Cox models with adherence to the SPE guidelines calculated using own bodyweight exercise only.
- We examined whether total activity is an effect modifier by including an aerobic physical activity*SPE term in fully adjusted Cox models and we performed stratified Cox analyses by physical activity level.
- As smoking is a causal risk factor for all three study outcomes and is significantly linked to participation of SPE, we also carried out a sensitivity analysis restricted to non-smokers.

RESULTS

Sample characteristics

The core sample comprised 80,306 participants corresponding to 736,463 person years and a mean follow-up of 9.2 (SD 4.5) years. Among them 36.2% met only the aerobic guidelines, 3.4% met only the SPE guidelines, and 5.5% met both. Characteristics of the core sample by overall SPE participation are presented in Table 1 (that includes all eligible participants prior to exclusions described below). Compared to non-participators, SPE participators were younger, had a slightly lower BMI, were less likely to have longstanding illness, be current smokers, be depressed, or to only meet the aerobic physical activity guideline; and more likely to have finished full-time education at age ≥19. In total, 1,891 participants had cancer and 5,292 had major CVD at baseline and were excluded from the corresponding analyses. Another 938 participants died in the first 24 months of the follow-up and were excluded from all further prospective analyses. The main analyses included 72,459 (all-cause mortality), 73,937 (CVD) and 77,195 (cancer mortality) participants.

Association between strength-promoting exercise and mortality

Figure 1 shows the fully adjusted associations between mutually exclusive categories of SPE and mortality. Own bodyweight SPE showed clearer associations than gym-based SPE in terms of all-cause and cancer mortality; compared to no SPE participation, participation in both types was linked with the largest all cause (0.51, CI: 0.33 to 0.79) and cancer (0.25, CI: 0.01 to 0.60) mortality risk reductions.

Table 2 presents the associations of own bodyweight SPE, gym-based, and total SPE with all-cause mortality. Participation in both SPE types was consistently associated with lower risk of all-cause mortality in both partially adjusted and fully adjusted models, with evidence for a modest dose-response association with higher volumes. Similarly, in fully adjusted models, the hazard ratio for low weekly volume of total SPE was 0.81 (CI: 0.69 to 0.95), and 0.75 (CI: 0.64 to 0.88) for higher weekly volumes.

All three SPE variables were associated with CVD mortality in the partially adjusted models but further adjustments materially attenuated these associations considerably (Table e3).

Table 3 presents the associations between SPE and cancer mortality. Own bodyweight (0.69, CI: 0.56 to 0.86) and gym-based (0.61, CI: 0.45 to 0.84) SPE were both associated with cancer mortality. Participation in any strength exercise was associated with cancer mortality in a dose-response manner.

There were no significant interactions between total physical activity and SPE participation in any outcomes (all P > 0.35). Among participants who did not meet the aerobic physical activity guideline (n=39,369), participation in any SPE was associated with a lower all-cause (fully adjusted HR: 0.76, CI: 0.65 to 0.89) and cancer (0.65, CI: 0.49 to 0.87) mortality. Among participants who met the aerobic guideline (n=33, 840), SPE was associated with all-cause (0.89, CI: 0.77 to 1.03) and cancer (0.75, CI: 0.59 to 0.95) mortality. In the sub-sample (n=33,063, 836 deaths /326 cancer deaths) with additional adjustment for fruit and vegetable consumption all associations between SPE and mortality outcomes observed in the full sample persisted. For example, the all-cause mortality hazard ratios for any SPE participation was 0.44 (CI: 0.25 to 0.77) and 0.60 (CI: 0.39 to 0.91) for own bodyweight SEP (data available on request).

Adherence to strength exercise and aerobic guidelines

Compared to not meeting the SPE guideline, adherence to the SPE guideline was associated with all-cause (0.80, CI: 0.70 to 0.91) (Table 2) and cancer (0.68, CI: 0.54, 0.86) (Table 3) mortality. These associations were materially unchanged when adherence to the guideline was calculated from own bodyweight SPE only (e.g. for all-cause and cancer mortality the hazard ratio was 0.81 (CI: 0.70 to 0.94) and 0.69 (CI: 0.54 to 0.90) respectively.

Figure 2 presents the fully adjusted comparisons between the aerobic physical activity and SPE guidelines with those adhering to neither guideline as the reference group. Adhering only to the SPE guideline was associated with lower risk of cancer (0.66, CI: 0.48 to 0.92) and to a lesser extent with lower risk of all-cause mortality (0.79, CI: 0.66 to 0.94). Adhering to the aerobic guideline only was associated with lower CVD (0.78, CI: 0.68 to 0.90) and all-cause (0.84, CI: 0.78 to 0.90) mortality. Adhering to both guidelines appeared to elicit additional risk reduction for all-cause (0.71, CI: 0.57 to 0.87),and cancer (0.70, CI: 0.50 to 0.98) mortality. Results in the analyses that employed the alternative definition of the aerobic guideline (>7.5 MET-hrs/week of any type and intensity) were broadly similar but also provided clearer evidence for an association between meeting both guidelines and CVD mortality (Figure e1). When we calculated adherence to the SPE guidelines using own bodyweight exercise only we observed similar differences between the associations that the SPE and aerobic guidelines exhibited with mortality (Figure e2).. Among non-smokers (n=54,285), the associations between gym-based SPE and all-cause mortality were attenuated compared to the main results presented in Table 2. The associations of all other SPE indicators (including adherence to the SPE guideline and participation in any SPE) with mortality in this sub-group analysis changed very little and not in a specific direction (Table e4).

DISCUSSION

The aim of this study was to investigate the association between the participation in SPE and all-cause, cancer and CVD mortality. SPE participation was linked with a 23% reduction in all-cause mortality and a 31% reduction in cancer mortality. In addition, there was some relatively modest evidence of dose-response relationship, with higher volume of SPE having a slightly greater reduction in all-cause mortality. Adherence to both the SPE and aerobic guidelines was associated with a greater risk reduction in mortality than aerobic physical activity alone (Figures 2 and e1). The lack of association between adherence to the aerobic guideline alone and cancer is surprising, given that previous studies suggest that the beneficial associations between total physical activity (SPE and aerobic combined) and overall cancer mortality often appear at amounts below the current recommendations (26, 27). One possibility is that, in the absence of SPE, amounts of aerobic activity in excess of 150 minutes of MVPA/7.5 MET-hours/week are needed to reduce cancer mortality risk. However, this interpretation is not supported directly by empirical evidence as we are not aware of any studies that have specifically assessed associations between adherence to the guidelines through aerobic physical activity only and cancer mortality. It is worth noting that muscle strength, the primary adaptation attributed to SPE, has been associated with reduced cancer mortality independent of aerobic fitness (28).

While the effects of aerobic exercise on morbidity, mortality and clinical health outcomes are well documented, much less focus has been given to SPE within a public health context (28). Our analysis showed that own bodyweight exercises that can be performed in any setting without equipment, yielded comparable results to gym-based activities (e.g. Figure 1). This has practical implications because strength training may be perceived as an activity primarily conducted within a gym or clinical setting where important participation barriers may be present, e.g. social inhibitions, limited access, and financial constraints (29). Our study also highlights likely gaps in public health practice as, with very few exceptions (28), studies estimating the prevalence (30) or burden (31) of physical inactivity as a chronic disease risk factor do not consider strength exercise in its own right. For example, when adherence to the SPE guideline is taken into account the prevalence of physical inactivity in Australia (28, 32) and U.S. (33) increases to ~80-85%, (vs. ~50% when only the aerobic guideline is taken into account).

Participants who adhered to the World Health Organization guidelines of 2 sessions of SPE per week had a 20% reduction in all-cause mortality. These findings are generally consistent with the 19% and 31% reduction in all-cause mortality reported by Kraschnewski et al (2016) (13) and Dankel et al (2016) (15), respectively. In contrast, we report a 49% reduction in cancer mortality, with Kraschnewski et al (2016) (13) showing no significant effect. Interestingly, we observed reductions in cancer mortality only in individuals who met the SPE but not the aerobic guidelines. Strength training has been shown to lower circulating levels of sex-hormones (34), reducing the risk of breast and endometrial cancer in women, and prostate cancer in men (35). In addition, strength training has also been shown to be a powerful adjunct therapy in the treatment of cancer, particularly to combat muscle dysfunction and cancer cachexia (36), as well as the side effects of anti-androgenic medication often prescribed in prostate cancer (37). SPE participation has been associated with a 33% reduction in all-cause mortality in cancer survivors (12). Taken together, SPE prior to diagnosis may reduce the risk of cancer mortality, but may also reduce all-cause mortality risk in cancer survivors. However, observational studies of SPE and cancer mortality in individuals free from a cancer diagnoses are lacking, and thus future studies are warranted on the effects of this modality of exercise on cancer mortality.

The present study showed a lack of evidence for an association of SPE with CVD mortality which is in agreement with previous literature (13, 15). However, participation in at least 30 minutes of SPE per week has been found to confer similar benefits in risk reduction as 2.5 hours of brisk walking for fatal and non-fatal myocardial infarction in men (11). Randomized controlled trials of resistance training have been shown to increase arterial stiffness in younger adults (38), with higher arterial stiffness associated with all-cause and CVD mortality (39). However, recent evidence show reductions in pulse wave velocity following 12-weeks of high or low intensity resistance training in younger men (40). Similarly, aortic reservoir pressure in pre-hypertensive and hypertensive older men was also shown to reduce following resistance training(41). Thus, the association between SPE and CVD mortality remain unclear and warrant further investigation. Thus, the effects of SPE on arterial stiffness remain heterogeneous, but it is possible that increases in arterial stiffness due to SPE may offset any potential benefit on other CVD risk factors such as reductions in blood pressure (42).

Previously in 8,772 adults, participation in 8-14 SPE sessions per month was associated with a reduction in all-cause mortality, with no benefit observed at higher frequencies (15). In our data there was some indication that higher volume and higher perceived intensity of SPE were associated with a greater reduction in all-cause and cancer mortality, respectively. Interestingly, higher muscle strength, as opposed to participation in SPE was found to be more strongly associated with reductions in mortality (14), suggesting the outcome of strength is more important than the behavior of SPE itself. This provides further evidence for a potential dose-response relationship, with experimental data (43) showing that SPE at higher volume and intensity have greater benefit on muscle strength. Experimental data on the isolated effects of progressive resistance training (PRT) on mortality are sparse. In an RCT of 124 older adults who had surgical repair of osteoporotic hip fracture, those who received PRT had a 81% and 84% reduction in mortality and nursing home admission respectively than those who received standard care (44). The anabolic response to high intensity PRT have been associated with improved glucose metabolism (45), reductions in systemic inflammation (46), reductions in depressive symptoms (47), improvements in cognitive function in adults with mild cognitive impairment (48) as well as aerobic capacity and functional and mobility outcomes (49), all of which can collectively reduce mortality risk.

Our study has utilized a pooled population sample and is one of the largest in the field of SPE epidemiology. We took robust approaches to minimize the chances for reverse causality (e.g. our analysis is the only one to exclude both prevalent disease cases and events occurring within the first two years) and performed several sensitivity analyses towards the same end, including adjustments for dietary factors in a sub-sample. A key limitation of this study was the use of self-reported assessment of strength exercise and the use of a 4-week recall time frame. Both of these characteristics of the exposure measurement may have resulted in regression dilution bias and attenuation of the “true” association between strength training and outcomes. At present there is no feasible substitute to the self-report assessments of SPE (50) which is the standard in public health surveillance (28, 51). The question on gym-based exercise enquired about some forms of aerobic exercise and while attempts were made to reduce measurement error by weighting estimation by the volume of SPE gym-based activity, we acknowledge the possibility that some aerobic activity was included. However, own bodyweight SPE showed similar of higher levels of mortality risk reduction (Figure 1) compared to the gym-based indicator; and calculating adherence to the SPE guideline using the own bodyweight indicator only did not materially change results (Figure e2). Both of these analyses support the robustness of our overall SPE findings.. SPE questions in the literature have ranged broadly from “weightlifting” (5, 6, 11), unspecified/unreported questions on “strength training” (11), specific questions on “calisthenics, free weights, or weight training machines” (12), specific questions on “physical activities specifically designed to strengthen your muscles, such as lifting weight or doing calisthenics” (13), or “physical activities specifically designed to strengthen your muscles, such as lifting weight, push-ups or sit-ups?” (14, 15). Our SPE measure included elements of weight training (5, 6, 11, 12) and calisthenics (12, 13, 14, 15) and as such it captures the elements previously used addressed in the literature.

Low statistical power may have compromised some of our results. For example, in the combined associations of SPE and aerobic guidelines with CVD mortality the group adhering to the SPE guideline *only* had 42 events (event rate 1.6%), although it is worth noting that in the case of cancer mortality we did detect an association in the same group despite the low number of events (38 events, event rate 1.4%).

In conclusion, participation in any SPE was associated with a 23% reduction in all-cause mortality and a 32% reduction in cancer mortality. In terms of mortality risk reduction, adherence to SPE guidelines appears to be at least as important as adherence to the aerobic guidelines. Our results support the value of specifically promoting adherence to the strength exercise guidelines over and above the generic physical activity targets.

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Figure Legends

Figure 1A-C: Fully adjusted[§] associations between mutually exclusive categories of strength promoting exercise types and mortality

[§] *Adjusted for age, BMI, educational attainment, presence of longstanding illness, weekly frequency of alcohol consumption, smoking habits, psychological distress/depression; and mutually adjusted for volume of all other (non-strength promoting) physical activity*

Figure 2A-C: Fully adjusted[†] associations of adherence to the aerobic[§] physical activity and strength promoting guidelines with mortality

[†] *Adjusted for age, BMI, educational attainment, presence of longstanding illness, weekly frequency of alcohol consumption, smoking habits, psychological distress/depression, and total volume of physical activity* *§ Reflecting moderate to vigorous physical activity only. Achieving at least 150 minutes/week of moderate intensity or 75 minutes/week of vigorous intensity or equivalent combinations of moderate and vigorous non-strength promoting physical activity denoted adherence to the aerobic guideline.*

Table 1. Baseline Characteristics of the Sample by Participation in Strength-Promoting Exercise. Adults Aged 30 Years and Over. The Health Survey for England and Scottish Health Survey (n=80,306).

	Overall participation in strength-promoting exercise [g]		
	Did not participate (n=68,222)	Participated (n=12,084)	*P* for Δ[f]
Age, mean (SD) (years)	53.0 (14.5)	45.6 (12.4)	<0.001
Sex (% female)	54.9	51.8	<0.001
Body mass index, mean (SD) (kg/m^2)	27.3 (4.9)	26.6 (4.2)	<0.001
Long standing illness [a] (%)	49.4	38.2	<0.001
Smoking (% current)[b]	26.1	17.8	<0.001
Alcohol frequency (% ≥5 times/week)[c]	19.4	19.8	0.341
Psychological distress (% with GHQ score ≥4)[d]	15.3	12.2	<0.001
Age finished education (% finished age 19+)	16.2	28.9	<0.001
Meeting the aerobic physical activity recommendation only (%)[e]	38.4	24.0	<0.001
Meeting the strength exercise recommendation only (%)[f]	N/A	22.5	
Meeting both physical activity recommendations (%) [e f]	N/A	36.2	

[a]Dichotomous variable derived from responses to a series of questions (yes/no) on illness within 8 listed body systems (eg. nervous system, digestive system, heart and circulatory system etc.). At least one illness required to have longstanding illness; [b]based on one question about smoking status with the options being: never smoker, ex-smoker, currently smoking 1-10/day, currently smoking 10-19/day, currently smoking ≥20/day; [c] derived from the question "on how many days in the last 7 days did you have an alcoholic drink; [d] General Health Questionnaire comprises 12 questions related to psychological health (eg. concentration, feeling depressed etc) the categories were 0, 1-3 and ≥4; [e] **Reflecting moderate to vigorous physical activity only**: at least 150 minutes/week of moderate intensity or 75 minutes/week of vigorous intensity or equivalent combinations of moderate and vigorous non-strength promoting / non-domestic physical activity ; [f] Participation in at least two sessions of strength promoting exercise per week [g] P-value calculated using Whitney U test for continuous and likelihood ratio chi-square test for categorical variables; [g] defined as participation for at least once in the last 4 weeks prior to the interview

Table 2: Associations Between Strength-Promoting Exercise and All-Cause Mortality. Adults Aged 30 Years and Over With

No Cancer or Cardiovascular Disease[a] at Baseline who Survived the First 24 Months of Follow-Up (n=72,459).

	Deaths/n	Model 1[c]		Model 2[d]	
		HR	**95% CIs**	**HR**	**(95% CIs)**
Own bodyweight exercises[f]					
Overall participation					
None	5518/65383	1.00		1.00	
Any	245/7076	0.67	0.59, 0.76	0.78	0.68, 0.88
P		*<0.001*		*<0.001*	
Weekly volume[b]					
None	5518/65383	1.00		1.00	
Low	102 /3539	0.66	0.54, 0.81	0.76	0.63, 0.93
High	143/3537	0.68	0.57, 0.80	0.79	0.67, 0.93
Trend P		*<0.001*		*0.033*	
Gym-based[e]					
Overall participation					
None	5658/65769	1.00		1.00	
Any	105/6690	0.60	0.49, 0 .73	0.75	0.62, 0.91
P		*<0.001*		*0.004*	
Weekly volume[c e]					
None	5658/65769	1.00		1.00	
Low	30/3284	0.63	0.49, 0.81	0.77	0.60, 0.99
High	41/3406	0.56	0.41, 0.76	0.71	0.52, 0.97
Trend P		*0.002*		*0.071*	
All Strength Exercise					
Overall participation					
None	5435/60938	1.00		1.00	
Any	326/11521	0.66	0.59, 0.74	0.77	0.69, 0.87
P		*<0.001*		*<0.001*	

Weekly volume [b e]					
None	5435/60938	1.00		1.00	
Low	165/5707	0.69	0.59, 0.81	0.81	0.69, 0.95
High	163/5814	0.63	0.54, 0.74	0.75	0.64, 0.88
Trend P		*<0.001*		*0.002*	
Adherence to strength exercise guideline[g]					
Do not meet the guideline	5536/65,681	1.00		1.00	
Meet the guideline	227/6778	0.68	0.60, 0.78	0.80	0.70, 0.91
P		*<0.001*		*0.001*	

[a] Prevalent cardiovascular disease was defined as doctor-diagnosed or self-reported (long standing illness module) ischemic heart disease, angina, or stroke; prevalent cancer was determined through cancer registration records or self-reported (long standing illness module) [b]Groups were [illegible] weekly volumes were weighted using age (10 year bands) and sex-specific "proportions of total gym-based activity that was "Strength work out at a gym using machines or free weights" derived from the Health Survey for England 2008 and 2012 datasets (see *Table e1*); [f] own bodyweight and gym-based strength promoting exercise are not mutually exclusive in this Table; [g] Participation in at least two sessions of strenghth promoting exercise per week. This analysis is adjusted as (c) and (d) above including weekly aerobic physical activity volume.

Table 3. Associations Between Strength-Promoting Exercise and Cancer Mortality. Adults Aged 30 Years and Over With No Cancer[a] at Baseline who Survived the First 24 Months of Follow-Up (n=77,195).

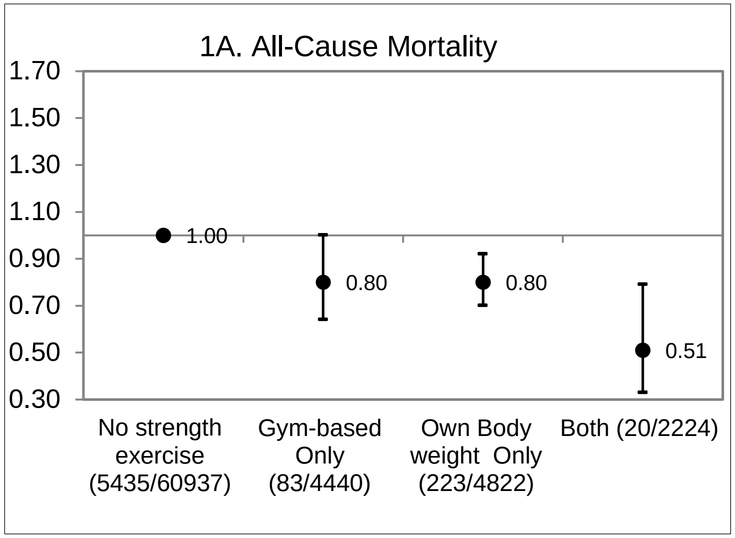
		Model 1[c]		**Model 2**[d]	
	Deaths/n	**HR**	**95% CIs**	**HR**	**95% CIs**
Own bodyweight exercises					

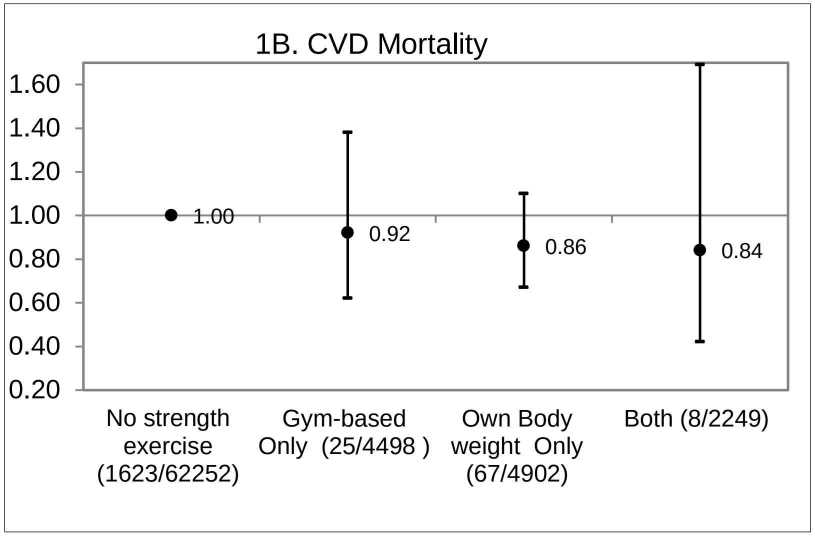
Overall participation					
None	2004 / 69917	1.00		1.00	
Any	85 / 7278	0.60	0.48, 0.75	0.69	0.56, 0.86
P		*<0.001*		*0.001*	
Weekly volume[b]					
None	2004 / 69917	1.00		1.00	
Low	36/3622	0.57	0.41, 0.79	0.66	0.47, 0.92
High	49/3656	0.63	0.47, 0.83	0.72	0.54, 0.96
Trend P		*0.019*		*0.076*	
Gym-based					
Overall participation					
None	2048/70358	1.00		1.00	
Any	41/6837	0.51	0.37, 0.69	0.61	0.45, 0.84
P		*<0.001*		*0.002*	
Weekly volume[c e]					
None	2048/70358	1.00		1.00	
Low	25/3375	0.55	0.37, 0.81	0.66	0.44, 0.98
High	16/3462	0.46	0.28, 0.75	0.56	0.34, 0.91
Trend P		*0.010*		*0.049*	
All Strength Exercise					
Overall participation					
None	1969 /65348	1.00		1.00	
Any	119/11847	0.59	0.49, 0.72	0.69	0.57, 0.84
P		*<0.001*		*<0.001*	
Weekly volume[b e]					
None	1969/65348	1.00		1.00	
Low	62/5884	0.62	0.48, 0.80	0.72	0.58, 0.93
High	58/5963	0.58	0.44, 0.75	0.67	0.52, 0.88
Trend P		*0.001*		*0.016*	

Adherence to strength exercise guideline[f]					
Do not meet the guideline	2012/70,230	1.00	.	1.00	
Meet the guideline	77/6965	0.59	0.47, 0.74	0.68	0.54, 0.86
P		*<0.001*		*<0.001*	

[a]Determined through cancer registration records or self-reported (using the long standing illness module); [b]Groups were defined using the sex-specific medians of the corresponding variable (see *Table e2*) [c]Model adjusted for age and sex [d]Model also adjusted for long-standing illness, alcohol drinking frequency, psychological distress, body mass index, smoking status, education level, and weekly physical activity volume excluding the volume of strength-promoting activity that is the main exposure in the corresponding model; [e]Gym-based exercise weekly volumes were weighted using age (10 year bands) and sex-specific proportions of total gym-based activity that was “Strength work out at a gym using machines or free weights” derived from the Health Survey for England 2008 and 2012 datasets (see *Table e1*); [f] participation in at least two sessions of strenghth promoting exercise per week. This analysis is adjusted as (c) and (d) above including weekly aerobic physical activity volume.

Figure 1


1A. All-Cause Mortality


1B. CVD Mortality

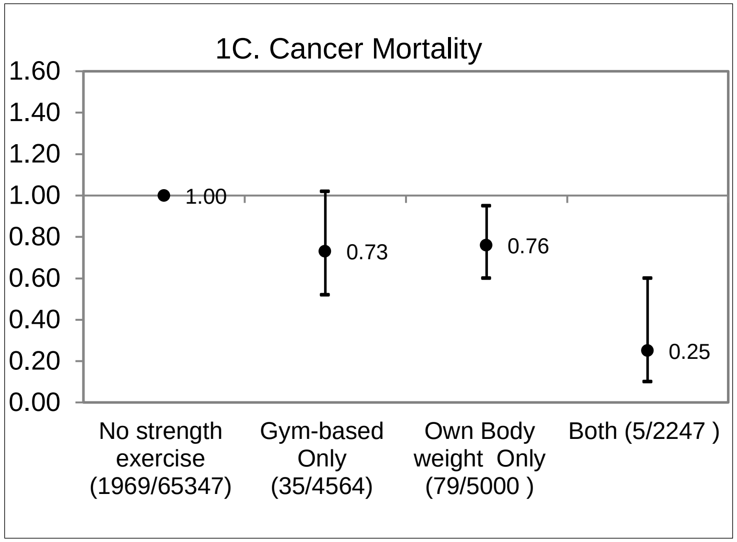
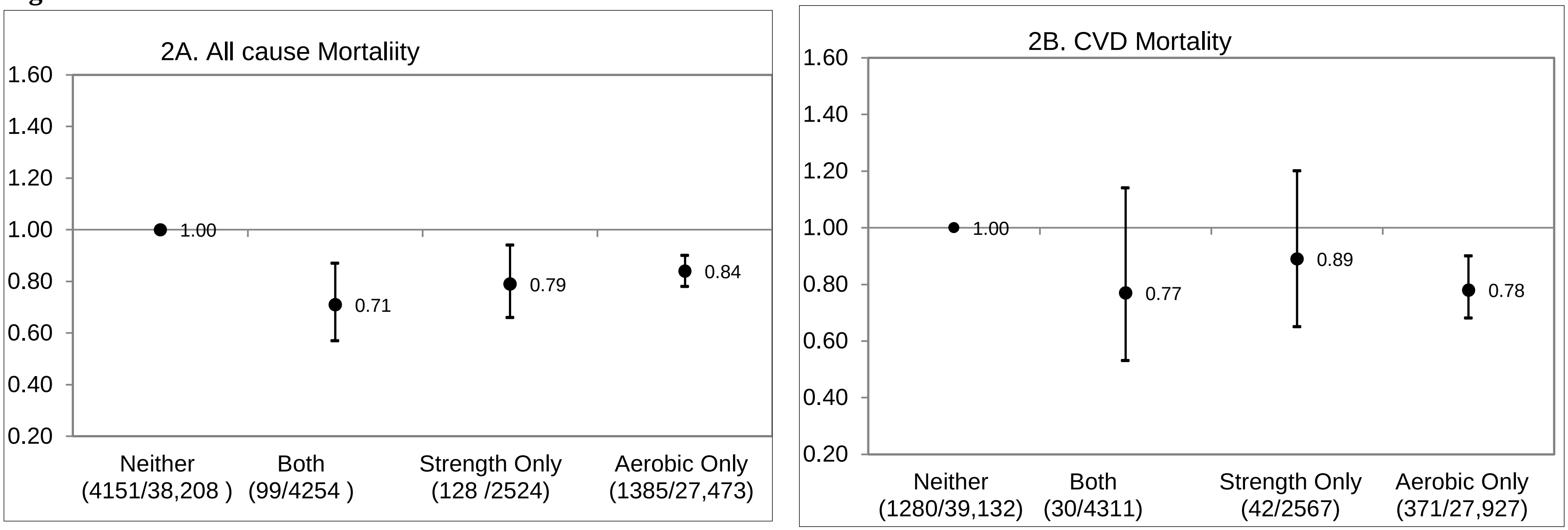
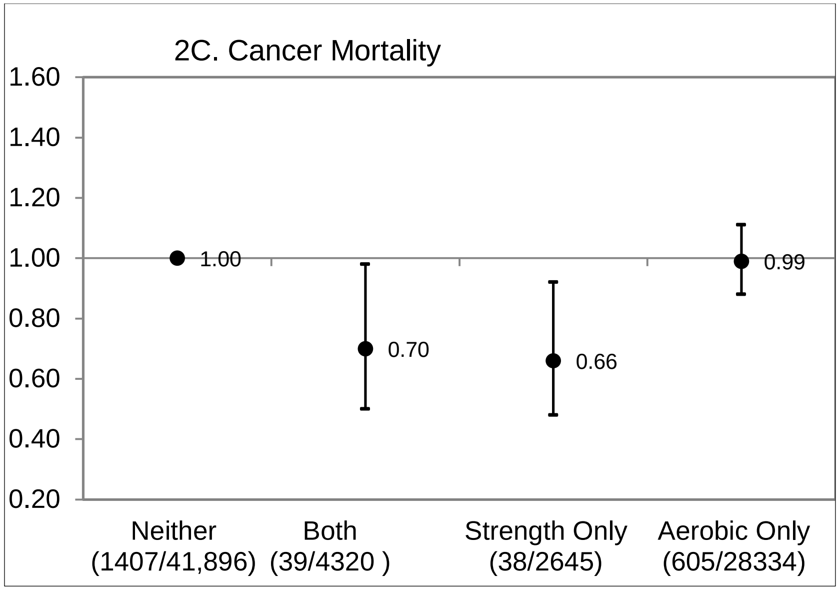

1C. Cancer Mortality

Figure 2


2A. All cause Mortaliity
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
1.00
0.71
0.79
0.84
Neither
(4151/38,208)
Both
(99/4254)
Strength Only
(128 /2524)
Aerobic Only
(1385/27,473)
2B. CVD Mortality
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
1.00
0.77
0.89
0.78
Neither
(1280/39,132)
Both
(30/4311)
Strength Only
(42/2567)
Aerobic Only
(371/27,927)


2C. Cancer Mortality
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
1.00
0.70
0.66
0.99
Neither
(1407/41,896)
Both
(39/4320)
Strength Only
(38/2645)
Aerobic Only
(605/28334)