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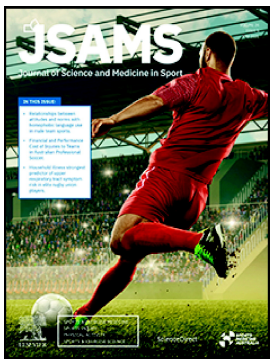

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Associations between muscle-strengthening exercise and prevalent chronic health conditions in 16,301 adults: Do session duration and weekly volume matter?

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Abstract

Objectives: Muscle-strengthening exercise (MSE) has multiple health benefits and is part of the global physical activity guidelines. However, with epidemiological research largely focussing on participation frequency (times/week), little is known about the health associations of other parameters. Hence, this study aimed to determine if MSE duration and volume are associated with prevalent chronic health conditions.

Design: Cross-sectional

Methods: Cross-sectional data (n=16,301 adults ≥16 years) were pooled from the Health Survey for England (2012, 2016). Respondents self-reported MSE mode (own-bodyweight, gym-based), duration and volume, and the prevalence of five chronic conditions (diabetes, anxiety/depression, heart, respiratory, or musculoskeletal condition). Poisson regressions with robust error variance were used to calculate the prevalence ratios (PR) of each chronic condition (outcome variable) across MSE parameters [exposure variables: duration (0 [reference]; 10-20; 21-59; ≥60minutes/session); and volume (0 [reference]; low <mean; high ≥mean minutes/week) for each mode and the modes combined.

Results: Most adults (81.5%) did no MSE. Undertaking any MSE regardless of mode, duration or volume was associated with a reduced likelihood of diabetes (APRs 0.25-0.39), heart (APRs -0.32-0.60), respiratory (APRs 0.49-0.67), and musculoskeletal conditions (APRs 0.43-0.63), and anxiety/depression (APRs 0.46-0.68). Associations remained after adjustment for potential socio-demographic and behavioural confounders.

Conclusion: While participation in own-bodyweight or gym-based-strength MSE is low, irrespective of mode, duration or volume, MSE was associated with a lower prevalence of chronic health conditions. Studies with longitudinal study designs are needed to confirm these cross-sectional findings.

Keywords: Chronic health conditions, Exercise, Muscle-strengthening exercise, Physical activity, Prevalence, Public Health

1. Introduction

Chronic diseases, such as hypertension, cardiovascular disease, type-2 diabetes, and depression, are leading causes of morbidity and mortality.[1] Regular physical activity (PA) participation is key in preventing and managing chronic disease.[2] The 2020 World Health Organization's (WHO) guidelines on PA and sedentary behaviour (SB) states adults (18–64 years) should not only engage in "moderate and/or vigorous-intensity aerobic physical activity" throughout the week, they should also undertake muscle-strengthening exercise (MSE) "at moderate or greater intensity" targeting "all the major muscle groups on two or more days a week".[3] Presently, most of the evidence on PA for health is based on the benefits of aerobic moderate-to-vigorous PA (aerobic-MVPA), with limited insight into other PA exercise-related behaviours, such as MSE.[3]

MSE is undertaken voluntarily by individuals during leisure-time, in multiple settings.[4] This exercise mode increases strength, power, endurance, or mass of skeletal muscle.[4] MSE typically involves using equipment such as weight machines, hand-held weights, resistance bands, or own-bodyweight.[4] Assessment of MSE within public-health-surveillance is relatively new compared to the assessment of aerobic PA[4 5], with data predominantly obtained through self-reported instruments.[4]

Strong clinical and emerging epidemiological evidence supports the performance of MSE in the efforts to reduce morbidity risks associated with chronic disease.[6] For example, clinical studies have shown that MSE is positively associated with metabolic health,[7] through improved glucose and lipid metabolism, and lowering of blood pressure.[8] Moreover, Gordon et al.,[9] identified a significant reduction in depressive symptoms for MSE participants. Additionally, epidemiological evidence has linked the benefits of undertaking MSE (independent of other PA modalities) with a reduced risk of mortality[10], diabetes[11], cardiovascular disease[12], and colon/kidney cancer.[13]

A limitation of current epidemiological evidence on MSE and health is that most studies implement a crude classification for MSE based on weekly frequency (0-1 vs. ≥2 times/week).[10, 14, 15] Clinical studies demonstrate that duration/session and volume/week of MSE may positively influence

health as well as increasing muscle mass/strength.[16] However, because these components are rarely assessed in population-based studies, there is limited understanding of the dose-dependent relationship that MSE volume has on participant health among population-surveillance.[3] Moreover, the influence that specific MSE modalities (such as using weight machines, or own-bodyweight) have on health is under-researched.[4]

This study aims to describe the association between the duration and volume of two MSE modalities (own-bodyweight, gym-based-strength) and the prevalence of common chronic health conditions (e.g., cardiovascular, mental health, and musculoskeletal), among a large population-based sample of adults.

2. Methods

The Health Survey for England (HSE) has been collecting health and related participant data from free-living members of the English population since 1991.[17] The HSE assesses PA every four years. This survey targets a nationally representative population consisting of English-speaking people aged ≥16 years, providing information regarding public-health trends, specified health conditions, and related prevalence rates.[18] HSE data are collected through a standardised survey instrument, administered face-to-face by trained researchers.[18] For this study, we pooled the two most recent HSE waves that included cross-sectional data for MSE activities (2012 and 2016) (*n*=20,400). These data have historic ethics approval from East Midlands Nottingham 2 Research Ethics Committee[17], and Oxford A Research Ethics Committee.[18] Informed consent was obtained from all participants.[19]

Our study used cross-sectional data from participants aged ≥16 years. Participants were excluded if they had missing age information (9.5%, *n*=4,099). Our final sample contained 16,301 individual participants.

MSE was assessed by self-report using an interview-administered questionnaire.[17, 18] To assess PA, respondents were initially shown a card (see Appendix-A)[18] and asked: *"Can you tell me if you have done any activities on this card during the last 4 weeks,? Please include teaching, coaching, training and practice sessions".* We selected MSE-related activities from the show card: *"Workout at a gym/Exercise bike/Weight training"* and *"Exercises (e.g. press-ups, sit-ups)"*.

Participants were then asked *"Can you tell me on how many separate days you did (name of activity) for at least 10 minutes a time during the past four weeks*"; and *"How much time did you usually spend doing (name of activity) on each day? Only count times you did it for at least 10 minutes".* If participants reported *"Workout at a gym/Exercise bike/ Weight training"* they were shown a card (see Appendix-B)[18] and asked: *"What did you do specifically?"*. Five options were provided (see Appendix-B)[18], in this study we selected *"Strength work out at a gym using machines or free weights"*. Participants were again asked about the frequency and duration spent doing the activity each day (for at least 10 minutes). Similar questions are used in other large population-surveillance surveys, which have shown evidence of excellent test-retest reliability (Cohen's kappa (κ)=0.85;95%CI:0.71-0.99) and moderate validity (κ=0.40;95%CI:0.20-0.60) for MSE.[20] Moreover, the HSE asks participants about times spent in 'weight-training' and 'using-free-weights'. Comparatively the Behavioral Risk Factor Surveillance System[20] asks respondents to report 'own-body-weight-exercises', 'weight-machines', 'free-weights' or 'elastic-bands'. Therefore, while there may be some minor differences between the MSE related modes assessed between instruments, each survey instrument is essentially measuring the same construct. For this study, we labelled *"Exercises (e.g. press-ups, sit-ups)"* as 'own-bodyweight exercises'; and *"Strength work out at a gym using machines or free weights"* as 'gym-based-strength exercise' (working out with weights). These data were then combined to create a third category 'total MSE' (total-MSE). For own-bodyweight exercises, gym-based-strength exercise, and total-MSE, session duration (minutes) data were collapsed into one of four groups: (i) none/0 minutes; (ii) low (10-20 minutes); (iii) moderate (21-59 minutes); or (iv) high (≥60 minutes) (see Table 1, Figure 1, Supplementary Table 1.1, Appendix-C, Appendix-D, and Appendix F).

For the volume of reported MSE (own-bodyweight and gym-based-strength), we first multiplied frequency (days in the last four weeks) by duration (session), then divided this total volume by four for the average weekly volume for each respective mode. For total-MSE, we first summed the total volume (own-bodyweight and gym-based-strength), then divided this by four to arrive at the average weekly volume for total-MSE. Consistent with previous research [21], we then derived the mean values for each of the three exposure variables: (i) own-bodyweight exercises (76.1 minutes/week [SE 4.09; SD 193.60]); (ii) gym-based-strength exercise (99.4 minutes/week [SE 3.74; SD 147.07]); and (iii) total-MSE (107.6 minutes/week [SE 3.79; SD 208.06]). The resulting data for each of the three exposure variables were then collapsed into one of three groups: (i) none; (ii) low (<mean minutes/week); or (iii) high (≥mean) (see Table 1, Supplementary Table 1.1, Figure 2, Appendix-C, Appendix-E and Appendix-G).

Participants were asked to self-report whether a health professional had told them that they had a chronic condition. Five chronic conditions, i.e., type-2 diabetes, conditions affecting the heart, respiratory and musculoskeletal systems, and anxiety/depression were chosen for our analyses. The selected chronic conditions, featured in the WHO's target non-communicable diseases reduction strategy, present a significant impact on rates of morbidity and mortality globally.[2] For diabetes, participants were asked "*Do you now have, or have you ever had diabetes?*" (yes/no). For conditions affecting the heart, respiratory and musculoskeletal systems and anxiety/depression participants were asked "*Do you have any physical or mental health conditions or illnesses lasting or expected to last 12 months or more?"* (yes/no). To calculate the number of chronic diseases, we combined the responses (yes/no) for each of the five conditions. These data were then collapsed into having either: (i) 0 conditions; (ii) 1 condition; or (iii) ≥2 conditions.

Sociodemographic, lifestyle factors, aerobic-MVPA participation, and SB were selected a priori, as previous literature has shown the possible influence these factors have on MSE participation.[22, 23] Sex was self-reported (male or female). As continuous age data was not available

for both waves, we used 'age in 10-year brackets'. Education was assessed as the highest level obtained or qualification. Total household income was equivalised into income tertiles. Alcohol consumption was collapsed into participants with either (i) 'less than weekly/not at all/non-drinkers', or (ii) 'weekly alcohol consumption'. Smoking status was collapsed into participants who (i) 'never smoked', (ii) 'ex-smoker', or (iii) 'current smoker'. Taking drugs prescribed for blood pressure was collapsed into participants (i) 'not taking drug' or (ii) 'taking drug'. For longstanding illness, participants were asked "*Do you have any physical or mental health conditions or illnesses lasting or expected to last 12 months or more?*". These data were collapsed into either (i) 'no' or (ii) 'yes'.

Objective anthropometric measurements included: (i) height (recorded to the nearest millimetre); and (ii) weight (recorded in kilograms and grams) and were assessed by a nurse, using standard measurement protocols.[17] We calculated body mass index (BMI), by dividing participant weight by their height in metres squared.[19] These data were further collapsed and reported as standard BMI classifications: (i) underweight <18.5kg/m^2; (ii) normal weight ≥18.5kg/m^2 to <25kg/m^2; (iii) overweight 25kg/m^2 to <30kg/m^2; and (iv) obese ≥30kg/m^2.

Aerobic-MVPA was reported in minutes/week, with this data combined and then collapsed into those participants who were classified as: (i) 'inactive' (0 minutes/week,), (ii) 'insufficiently active' (1-149 minutes/week) and not meeting the guideline or (iii) 'active' (≥150 minutes/week).[24] For sedentary time, participants self-reported their daily (i) time spent watching TV; and (ii) time spent in any other sitting on both a usual weekday and weekend day. We combined the data for these two contexts, into 'time spent sitting (in minutes)' on a weekday and a weekend day. Then collapsed these data into total sedentary time using the following formula: (weekday sitting time x 5 + weekend sitting x 2). For our analysis, we collapsed these into either: (i) low SB (<3,359 minutes/week); or (ii) high SB (≥3,360 minutes/week). Based on existing literature,[25] high SB was classed if the respondent self-reported ≥480 minutes/day.

We pooled cross-sectional data from the 2012 and 2016 HSE waves. SPSS version 26 (SPSS Inc., an IBM Company, Armonk, NY) was used for all analyses. Descriptive statistics were used to describe the profile of the sample according to the covariates and outcome variables (see Supplementary Table 1) and the MSE exposure variables (see Table 1). Throughout, significance was set at $p<0.05$.

To analyse the associations of the respective modes/duration/volume of MSE with the individual/multiple chronic health conditions, we used Poisson regression analysis, with robust error variance to calculate prevalence ratios (PR) with their 95% confidence intervals (CI). Due to the binary nature of having an adverse health condition (yes vs. no), Poisson regression examined the PR for each chronic health condition (outcome variable) according to the three MSE categories (exposure variable). The reference category was those doing no MSE (duration=0 minutes/session; and volume=none).

To examine the effects of covariates, we conducted four models: Model-A 'unadjusted', Model-B (adjusted for sociodemographic factors: sex; age; education; and income tertiles); Model-C (adjusted for Model-B and lifestyle factors: BMI; weekly alcohol consumption; smoking status; taking blood pressure medication; and longstanding illness); and Model-D (adjusted for Model-C in addition to weekly aerobic MVPA and weekly sedentary time). Before conducting our analysis, we tested for multicollinearity among potential covariates and the five chronic conditions using tests for the variance inflation factor (VIF), with VIF ≥2 indicating multicollinearity.[26] The VIF values ranged from 1.05 to 1.31, indicating no evidence of collinearity.

3. Results

Data from 16,301 adults aged 16-75 years+ were included in our analysis. The participant characteristics are shown in Supplementary Table 1. In brief, over half were female (55.6%), aged between 16-54 years (59.3%), and classified overweight/obese (63.7%). Approximately half had never smoked and just under three quarters self-reported not having a longstanding illness. Well over

half were considered 'active' in aerobic-MVPA. Approximately '10%' of participants reported having diabetes, a heart or respiratory condition, and around '20%' reported having a musculoskeletal condition or anxiety/depression. Over a quarter of participants reported having at least one chronic condition, with approximately '15%' reporting ≥2 chronic conditions.

Table 1 describes the MSE behavioural characteristics of the participants. Briefly, >80% reported doing no own-bodyweight exercise, and >90% reported doing no gym-based-strength exercise. Participants reporting own-bodyweight exercise or gym-based-strength exercise mostly completed their exercise in bouts of 10-20 minutes duration.

The unadjusted and adjusted prevalence ratios (APRs) and their 95% (CI) for each of the health conditions (diabetes, heart condition, respiratory condition, musculoskeletal condition, anxiety/depression), and number of chronic conditions (1 condition, ≥2 conditions), are shown in Appendix-C. The prevalence ratios (PRs) were similar after adjusting for confounders. Therefore here we will only present the results of the most adjusted model (Model-D).

For diabetes, shown in Figure 1-Panel A, compared to the reference group (0 minutes), the APRs followed an inverse linear-gradient for own-bodyweight (APRs 0.40,95%CI[0.25-0.59]; 0.36,95%CI[0.17-0.68]; 0.26,95%CI[0.06-0.66]) and total-MSE, (0.47,95%CI [0.30-0.68]; 0.39,95%CI [0.23-0.62]; 0.31,95%CI [0.15-0.57]) session duration. However, for gym-based-strength session duration, the APRs for diabetes was lowest among those reporting 21-59 minutes (APR=0.31,95%CI [0.13-0.61]). For volume, PRs and APRs were very similar for each MSE mode (see Appendix-C, and Figure 2-Panel A).

For a heart condition, in each MSE category, the APRs followed an inverse linear-gradient (see Figure 1-Panel B) for minutes/session (APRs ranged from 0.58-0.19 across the three modes) when compared to those who did none. For volume, APRs were mixed, with high volumes of gym-based-strength (APR=0.22,95%CI[0.09-0.44]) and total-MSE (APR=0.30,95%CI[0.18-0.48]) having

a lower likelihood for a heart condition, compared to own-bodyweight (APR=0.45,95%CI[0.33-0.59]) for <mean (low volume) (see Figure 2-Panel B), however, all were lower when compared to the reference group (none).

For a respiratory condition, (see Figure 1-Panel C), compared to the reference group (none), participants reporting 60+ minutes of own-bodyweight exercise (APR=0.55,95%CI[0.24-1.08]); 21-59 minutes of gym-based-strength exercise (APR=0.44,95%CI[0.23-0.76]), and people reporting both modes (total-MSE, APR=0.47,95%CI[0.30-0.71]) had a lower likelihood for a respiratory condition. For volume, compared with the sample who did none, both those with a low and high volume had a lower likelihood for a respiratory condition for gym-based-strength (APR=0.49,95%CI[0.23-0.89]) and total-MSE (APR=0.52,95%CI[0.31-0.80]), whereas, for participants undertaking own-bodyweight exercise, this was only true for those with a low volume (APR=0.57,95%CI[0.41-0.77]) (see Figure 2-Panel C).

For a musculoskeletal condition (Figure 1-Panel D), 10-20 minutes of own-bodyweight exercises (APR=0.53,95%CI[0.42-0.67]) 60+ minutes of gym-based-strength (APR= 0.33,95%CI[0.16-0.58]), and 60+ minutes of all MSE (APR=0.45,95%CI[0.31-0.64]) were associated with the lowest likelihood of a musculoskeletal condition when compared with the respective reference groups (0 minutes). For volume, the likelihood of having a musculoskeletal condition was lowest among those doing a high volume of gym-based-strength (APR=0.30,95%CI[0.16-0.50]) and total-MSE (APR=0.46,95%CI[0.32-0.63]), whereas doing a low volume of own-bodyweight exercise (APR=0.53,95%CI[0.43-0.66]) seemed to be better than doing high volumes (see Figure 2-Panel D) compared to the reference group (none).

For anxiety/depression (Figure 1-Panel E) compared to the duration reference group (0 minutes), participants reporting 60+ minutes of own-bodyweight exercise (APR=0.34,95%CI[0.12-0.73]) or total-MSE (APR=0.46,95%CI[0.27-0.72]) had the lowest likelihood of having anxiety/depression, whereas those doing 21-59 minutes of gym-based-strength exercise had the lowest

likelihood (APR=0.39,95%CI[0.21-0.66]). For volume, all APRs are lower when compared to those reporting none (reference group) (see Figure 2-Panel E), however, the APRs seem lowest for doing <mean (low volumes) than for the high volumes for each MSE category (APRs ranging from 0.38-0.51).

In the fully adjusted model (Model-D), the lowest likelihood of having multiple (≥2) chronic conditions, (see Figure 1-Panel F) compared to the reference group (0 minutes), the APRs were mixed, with undertaking 60+ minutes of own-bodyweight (APR=0.1[illegible]95%CI[0.03-0.48]) or total-MSE (APR=0.09,95%CI[0.02-0.24]) representing the lowest likelihood for ≥2 chronic conditions, whereas those reporting 21-59 minutes of gym-based-strength (APR=0.07,95%CI[0.01-0.23]) had the lowest likelihood for ≥2 chronic conditions for that exercise mode. For volume, (see Figure 2-Panel F) the resulting APRs were similar, when compared to the reference group, for both low (<mean) and high (≥mean) volume across all three modes.

Age-based stratified analysis, based on the most adjusted model (Model-D) and total-MSE, was completed for each of the five chronic conditions, and having one or two or more chronic conditions (see Appendix-F and Appendix-G). Overall, with minimal exceptions, the results are similar across all conditions. In brief, for both duration/session and volume/week the lowest APRs were observed amongst 16-54-year-olds for those reporting having a heart condition (APR=0.08[95%CI 0.00-0.57], 0.08[95%CI 0.00-0.34]) when compared to adults aged 55+ years. However, the lowest APRs (for duration/session and total volume/week) were observed amongst adults aged 55+ years reporting anxiety/depression (APR=0.16[95%CI0.01-0.70], 0.36[95%CI0.09-0.93] when compared to adults aged 16-54 years.

4. Discussion

The key finding was that compared to those doing no or insufficient MSE, with minimal exceptions, irrespective of mode, volume, or duration, engaging in this exercise modality for ≥10

minutes was associated with a lower likelihood of chronic conditions. Moreover, these associations remained after adjustment for age, sex, BMI, smoking, alcohol, aerobic-MVPA, and sedentary time. While these data need to be confirmed in future prospective studies, our cross-sectional study suggests that MSE at any volume and duration or mode is likely to have health benefits.

While there is a large body of evidence describing the relationship between volume and duration of aerobic-MVPA and health, the corresponding relationship with MSE is less understood.[4 5] With most of the evidence on MSE and health-based assessments of weekly frequency (0-1 vs. ≥2 times/week)[10, 14, 15], the current study is important because it is the first to provide an insight into other participation parameters and their relationship with health.

While our study shows overall that there was minimal difference between volume and duration and the likelihood of individual health conditions, there were some discrepancies observed. In brief, our findings suggest a lower likelihood for heart, respiratory or musculoskeletal conditions, or multiple chronic conditions, among those undertaking high volumes/week of total-MSE. Whereas those with diabetes, anxiety/depression, or having one chronic condition, completing a low volume/week of total-MSE had the most favourable association. Age-stratified associations remained consistent for both diabetes and those with one chronic condition, however, mixed for all other conditions (heart, respiratory, musculoskeletal, anxiety/depression, and having two or more chronic conditions). For comparison, there is limited research amongst large population samples on the dose-dependent relationship of MSE session duration and health. Our findings are somewhat consistent with Minges et al., which also did not show a clear dose-dependent association between MSE duration and impaired glucose metabolism.[7] However, they did not differentiate between different modes of MSE.[7] Our recent systematic review [27] highlighted several limitations in the way MSE is currently assessed in large population health-surveillance. For example, while the HSE obtains participant data concerning MSE intensity, the question limits response options to either yes or no (i.e., "*During the past four weeks, was the effort of … usually enough to make you out of breath or sweaty?"*). Future population-level research may benefit from the inclusion of additional MSE factors (e.g., perceived

exercise intensity, set/repetition volume, modes/exercise type), to gain a greater understanding of the potential relationship that these factors may have on health-related outcomes, such as NCDs.

Worldwide, prevalence rates for MSE participation are low when compared to self-reported aerobic-MVPA participation.[4] Approximately 26% of our sample were assessed as meeting the MSE guideline of ≥2sessions/week (however this percentage may be lower as some reported MSE may have performed at less than a moderate intensity), compared to 59.4% who met the aerobic-MVPA guideline. Globally, recommendations for adult MSE participation remain at ≥2times/week.[3] Moreover, there is a lack of evidence supporting higher frequencies of MSE for health.[3] Albeit cross-sectional, our data is among the first to show a similar relationship with MSE duration and volume and associations between the prevalence of health conditions. While further research is needed, this finding is important because it provides some preliminary insights into parameters of MSE beyond frequency and their associations with health.

For the promotion of MSE, our data suggest that small-to-moderate increases in MSE at the population-level are likely to have health benefits. Furthermore, our data suggest that this is the case irrespective of MSE mode. Therefore, to increase MSE participation, the focus of PA messaging must align with those promoted in the 2020 WHO 'good practice statements'[28] that state "doing some is better than doing none". Moreover, highlighting that MSE is not limited to a gym/fitness centre environment and can be undertaken by performing simple bodyweight exercises in the home.[29]

A key strength of this study is that it is the first to explore the relationship between specific MSE modes and adverse health outcomes, in a large population sample of adults. We have used data obtained through standardised recruitment and data collection procedures, therefore our findings can be compared with future HSE data and other large population-surveillance studies.

The key limitation of this study was the use of cross-sectional analyses, hence causality cannot be inferred. Our results should therefore be used with caution. Additional limitations include the risk of responder recall bias, through self-reported responses (e.g., social desirability or over/under-reporting of actual behaviour) and the indicator of having a chronic condition/s does not account for the temporality/severity of the condition/s. A further limitation was the non-assessment of MSE for durations less than 10 minutes, nor MSE intensity. Additionally, we are unable to exclude data from 16-17-year-old participants from our analyses.

5. Conclusion

Among a large community-based sample of adults, regardless of mode, volume, or duration, any MSE was associated with a lower likelihood of prevalent chronic diseases. While these findings need to be confirmed in prospective cohort studies, our findings suggest that small-to-moderate increases in MSE at the population-level are likely to have public-health benefits.

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Supplementary Table 1: Characteristics of participants included in the analysis [a]

Total sample of 2012 and 2016 Health Survey for England (n = 16,301)	
Total	**% (n)**
Sex	
Male	44.4 (7,232)
Female	55.6 (9,069)
Age (years)	
16-54	57.7 (9,402)
≥55	42.3 (6,899)
Education	
Graduate /degree	25.2 (4,093)
Higher education (below degree)	10.2 (1,651)
A or O level [b]	31.6 (5,131)
Other grade	3.8 (610)
Foreign/other	1.4 (234)
No qualification	22.1 (3,592)
Student (full-time)	5.8 (937)
Income Tertiles	
Highest	35.0 (4,420)
Middle	32.5 (4,106)
Lowest	32.5 (4,106)
Body Mass Index (kg/m^2)	
Underweight (<18.5)	1.6 (218)
Normal (≥18.5-<25)	34.6 (4,631)
Overweight (25– <30)	36.9 (4,940)
Obese (≥30)	26.8 (3,588)
Smoking status	

Never smoked	50.2 (8,120)
Ex-occasional smoker	5.1 (820)
Ex-regular smoker	26.7 (4,314)
Current smoker	18.1 (2,920)
Alcohol	
None (0)	17.8 (2,884)
Weekly	52.8 (8,530)
Monthly/Yearly	29.4 (4,749)
Cardiovascular medication	
Yes	18.6 (1,960)
No	81.4 (8,559)
Longstanding illness	
Yes	26.1 (4,256)
No	73.9 (12,033)
Aerobic-MVPA level (minutes/week)	
0minutes/week 'inactive'	24.3 (3,912)
1-149 minutes/week 'insufficiently active'	16.3 (2,635)
≥ 150 minutes/week 'active'	59.4 (9,574)
Sedentary behavior (min/day	
Low (<480 minutes/day)	87.1 (14,142)
High (≥480 minutes/day)	12.9 (2,087)
Chronic conditions (yes)	
Diabetes	7.8 (1,273)
Heart condition	12.3 (2,006)
Respiratory condition	7.9 (1,285)
Musculoskeletal condition	18.2 (2,959)
Anxiety/depression (2012 only)	20.2 (1,493)

Number of Chronic conditions	
0	57.7 (4,254)
1	26.3 (1,937)
≥2	16.1 (1,188)

[a] Numbers vary slightly because of missing data for some characteristic variables

Missing data equated to: 0.3% education (53), household income 22.5% (3,669), BMI 17.9% (2,924), alcohol consumption 0.8% (138), smoking status 0.8% (127), cardiovascular medication 35.5% (5,782), longstanding illness 0.1% (12), aerobic-MVPA 1.1% (180), sedentary behaviour 0.4% (72), diabetes 0.1% (12), heart condition 0.0% (8), respiratory condition 0.0% (8), musculoskeletal 0.0% (8) and anxiety/depression 54.7% (8,911)

[b] A or O level – 'A Level' is a pre-university qualification that is equivalent to 13 years of study. 'O' level typically represents a total of 11 years of study and signifies the completion of compulsory secondary education.

Table 1: Muscle-strengthening exercise behaviour characteristics (exposure variable) of participants included in the analysis

Total sample of 2012 and 2016 Health Survey for England (n = 16,301)	
Total	**% (n)**
Muscle- strengthening exercise – Session duration	
Own-Bodyweight (minutes/session)	
0 minutes	86.2 (14,057)
10-20 minutes	8.6 (1,406)
21-59 minutes	3.3 (533)
60+ minutes	1.9 (305)
Gym-based-strength (minutes/session)	
0 minutes	90.5 (14,752)
10-20 minutes	3.7 (603)
21-59 minutes	3.4 (558)
60+ minutes	2.4 (388)
Total-MSE (minutes/session)	
0 minutes	81.5 (13,285)
10-20 minutes	7.8 (1,278)
21-59 minutes	6.0 (982)
60+ minutes	4.6 (756)
Muscle- strengthening exercise – Weekly volume	
Own-Bodyweight (minutes x frequency)	
None	86.2 (14,057)
Low < mean	10.3 (1,672)
High ≥ mean	3.5 (572)
Gym-based-strength (minutes x frequency)	
None	90.5 (14,757)

Low < mean	6.5 (1,062)
High ≥ mean	3.0 (482)
Total-MSE (minutes x frequency)	
None	81.5 (13,287)
Low < mean	13.4 (2,177)
High ≥ mean	5.1 (837)

MSE: muscle-strengthening exercise

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

Mean values: own-bodyweight 76.1 min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week

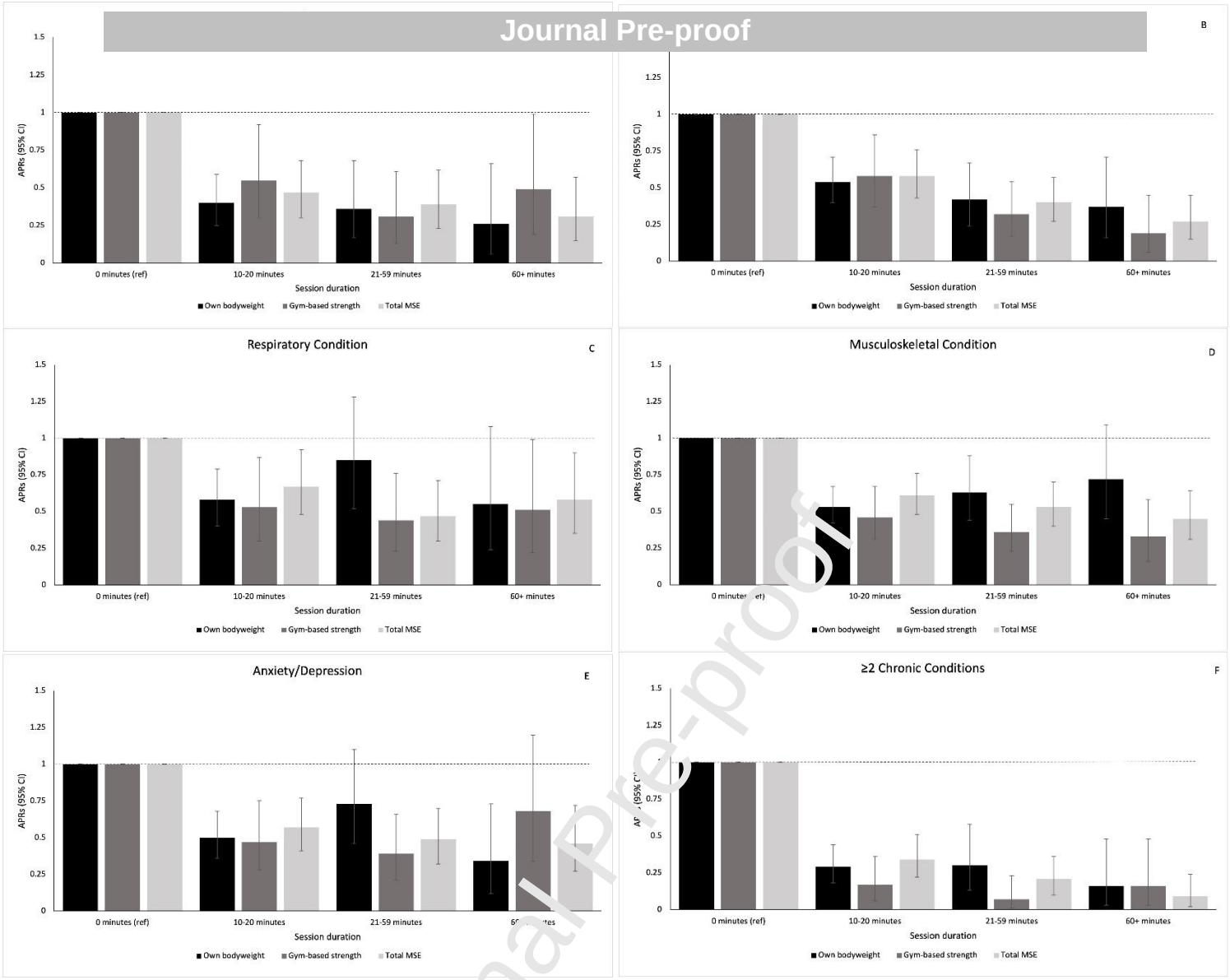

Figure 1; (Panels A-F). Analysis of the relationship between muscle-strengthening exercise (duration/session) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two modes combined (APRs; 95%CI).

APRs: adjusted prevalence ratios
MSE: muscle-strengthening exercise
Total-MSE = own-bodyweight exercise + gym-based-strength

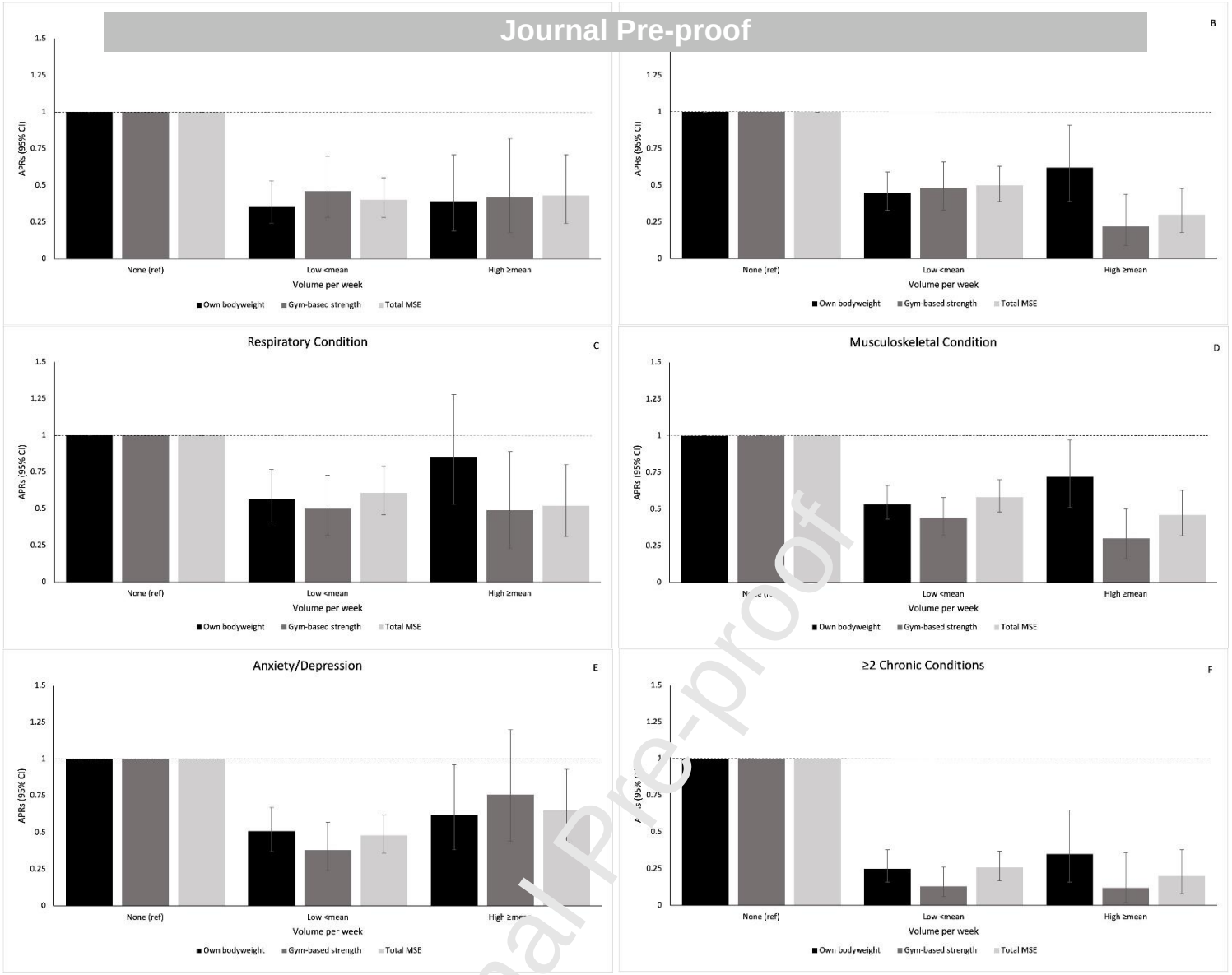

Figure 2; (Panels A-F). Analysis of the relationship between muscle-strengthening exercise (volume/week: frequency/week x duration/session) between five chronic conditions and having two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and combined (APRs; 95%CI).

APRs: adjusted prevalence ratios

MSE: muscle-strengthening exercise

Total-MSE = own-bodyweight exercise + gym-based-strength

Mean values: own-bodyweight 76.1 min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week

Appendix-A. Health Survey for England exercise show card E6

CARD E6

1 Swimming

2 Cycling

3 Workout at a gym/Exercise bike/Weight training

4 Aerobics/Keep fit/Gymnastics/ Dance for fitness

5 Any other type of dancing

6 Running/Jogging

7 Football/Rugby

8 Badminton/tennis

9 Squash

10 Exercises (e.g. press-up, sit-ups)

ActPhy/WhtAct

Appendix-B. Health Survey for England exercise show card E7

CARD E7

1 Strength work out at the gym using machines or free weights

2 Exercise Bike

3 Spinning Classes

4 Stepping machine, rowing machine or cross trainer

5 Treadmill running

WorkOut

Appendix-C

Analysis of the relationship between muscle-strengthening exercise (duration/session and volume/week) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two models combined (PRs; APRs; 95%CI) significance is indicated by *.

Diabetes				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.35 (0.25-0.47) *	0.37 (0.26-0.51) *	0.39 (0.25-0.58) *	0.40 (0.25-0.59) *
21-59 minutes	0.37 (0.22-0.58) *	0.35 (0.19-0.58) *	0.36 (0.16-0.67) *	0.36 (0.17-0.68) *
60+ minutes	0.27 (0.11-0.52) *	0.29 (0.12-0.60) *	0.25 (0.06-0.65) *	0.26 (0.06-0.66) *
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.46 (0.30-0.69) *	0.47 (0.28-0.73) *	0.54 (0.30-0.90) *	0.55 (0.30-0.92) *
21-59 minutes	0.32 (0.19-0.52) *	0.30 (0.16-0.52) *	0.31 (0.13-0.61) *	0.31 (0.13-0.61) *
60+ minutes	0.23 (0.13-0.50) *	0.38 (0.18-0.69) *	0.48 (0.10 0.98)	0.49 (0.19-0.99)
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.39 (0.28-0.52) *	0.42 (0.29-0.57) *	0.46 (0.30-0.67) *	0.47 (0.30-0.68) *
21-59 minutes	0.35 (0.24-0.50) *	0.33 (0.21-0.49) *	0.38 (0.22-0.61) *	0.39 (0.23-0.62) *
60+ minutes	0.25 (0.15-0.39) *	0.32 (0.19-0.50) *	0.31 (0.15-0.56) *	0.31 (0.15-0.57) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				

None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.33 (0.25-0.44) *	0.33 (0.24-0.46) *	0.36 (0.23-0.52) *	0.36 (0.24-0.53) *
High ≥ mean	0.37 (0.22-0.56) *	0.40 (0.23-0.65) *	0.39 (0.18-0.70) *	0.39 (0.19-0.71) *
Gym-based-strength exercises				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.40 (0.28-0.55) *	0.40 (0.26-0.57) *	0.45 (0.28-0.70) *	0.46 (0.28-0.70) *
High ≥ mean	0.30 (0.16-0.50) *	0.37 (0.19-0.64) *	0.42 (0.18-0.81) *	0.42 (0.18-0.82) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.34 (0.26-0.43) *	0.35 (0.26-0.45) *	0.39 (0.27-0.54) *	0.40 (0.28-0.55) *
High ≥ mean	0.35 (0.23-0.50) *	0.41 (0.26-0.61) *	0.43 (0.24-0.70) *	0.43 (0.24-0.71) *

Anxiety/Depression (only for 2012)				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.63 (0.51-0.78) *	0.59 (0.46-0.75) *	0.49 (0.35-0.67) *	0.50 (0.36-0.68) *
21-59 minutes	0.69 (0.48-0.96) *	0.68 (0.45-0.97) *	0.72 (0.45-1.08)	0.73 (0.46-1.10)
60+ minutes	0.44 (0.24-0.72) *	0.35 (0.17-0.63) *	0.33 (0.12-0.71) *	0.34 (0.12-0.73) *
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.61 (0.43-0.83) *	0.58 (0.39-0.82) *	0.46 (0.27-0.74) *	0.47 (0.28-0.75) *
21-59 minutes	0.53 (0.36-0.75) *	0.50 (0.32-0.74) *	0.39 (0.21-0.66) *	0.39 (0.21-0.66) *
60+ minutes	0.50 (0.29-0.79) *	0.50 (0.27-0.82) *	0.65 (0.33-1.15)	0.68 (0.34-1.20)

Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.68 (0.55-0.84) *	0.64 (0.50-0.81) *	0.57 (0.41-0.76) *	0.57 (0.41-0.77) *
21-59 minutes	0.56 (0.42-0.73) *	0.56 (0.41-0.74) *	0.48 (0.32-0.69) *	0.49 (0.32-0.70) *
60+ minutes	0.46 (0.32-0.64) *	0.42 (0.27-0.61) *	0.45 (0.27-0.70) *	0.46 (0.27-0.72) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.62 (0.51-0.75) *	0.59 (0.47-0.73) *	0.50 (0.37-0.66) *	0.51 (0.37-0.67) *
High ≥ mean	0.60 (0.42-0.84) *	0.54 (0.35-0.[illegible]) *	0.62 (0.37-0.95) *	0.62 (0.38-0.96) *
Gym-based-strength exercises				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.54 (0.41-0.70) *	0.52 (0.38-0.68) *	0.38 (0.24-0.56) *	0.38 (0.24-0.57) *
High ≥ mean	0.61 (0.40-0.[illegible]) *	0.58 (0.36-0.88) *	0.73 (0.43-1.16)	0.76 (0.44-1.20)
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.5[illegible] (0.49-0.71) *	0.57 (0.47-0.70) *	0.47 (0.35-0.61) *	0.48 (0.36-0.62) *
High ≥ mean	0.59 (0.43-0.77) *	0.53 (0.37-0.72) *	0.64 (0.42-0.92) *	0.65 (0.43-0.93) *

Heart Condition				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)

10-20 minutes	0.54 (0.44-0.66) *	0.54 (0.43-0.68) *	0.54 (0.40-0.70) *	0.54 (0.40-0.71) *
21-59 minutes	0.46 (0.31-0.63) *	0.47 (0.31-0.68) *	0.41 (0.24-0.66) *	0.42 (0.24-0.67) *
60+ minutes	0.47 (0.29-0.72) *	0.47 (0.27-0.76) *	0.41 (0.19-0.76) *	0.37 (0.16-0.71) *
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.48 (0.34-0.65) *	0.51 (0.35-0.71) *	0.57 (0.37-0.84) *	0.58 (0.37-0.86) *
21-59 minutes	0.33 (0.21-0.48) *	0.33 (0.20-0.50) *	0.32 (0.17-0.54) *	0.32 (0.17-0.54) *
60+ minutes	0.20 (0.10-0.35) *	0.16 (0.06-0.33) *	0.19 (0.06-0.44) *	0.19 (0.06-0.45) *
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.60 (0.49-0.73) *	0.60 (0.47-0.74) *	0.58 (0.43-0.76) *	0.58 (0.43-0.76) *
21-59 minutes	0.37 (0.28-0.49) *	0.38 (0.27-0.52) *	0.39 (0.26-0.56) *	0.40 (0.27-0.57) *
60+ minutes	0.33 (0.23-0.45) *	0.32 (0.21-0.46) *	0.29 (0.16-0.47) *	0.27 (0.15-0.45) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.48 (0.39-0.58) *	0.47 (0.38-0.59) *	0.44 (0.33-0.58) *	0.45 (0.33-0.59) *
High ≥ mean	0.61 (0.45-0.81) *	0.64 (0.46-0.88) *	0.63 (0.41-0.92) *	0.62 (0.39-0.91) *
Gym-based-strength exercises				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.42 (0.32-0.54) *	0.42 (0.30-0.55) *	0.47 (0.32-0.65) *	0.48 (0.33-0.66) *
High ≥ mean	0.21 (0.11-0.34) *	0.23 (0.12-0.40) *	0.21 (0.08-0.43) *	0.22 (0.09-0.44) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)

Low < mean	0.51 (0.43-0.60) *	0.50 (0.41-0.60) *	0.50 (0.39-0.63) *	0.50 (0.39-0.63) *
High ≥ mean	0.32 (0.23-0.44) *	0.36 (0.24-0.50) *	0.31 (0.19-0.49) *	0.30 (0.18-0.48) *

Respiratory Condition				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.57 (0.44-0.73) *	0.56 (0.42-0.73) *	0.58 (0.41-0.79) *	0.58 (0.40-0.79) *
21-59 minutes	0.72 (0.50-1.01)	0.82 (0.56-1.17)	0.87 (0.55-1.31)	0.85 (0.52-1.28)
60+ minutes	0.67 (0.40-1.04)	0.67 (0.38-1.09)	0.61 (0.28-1.15)	0.55 (0.24-1.08)
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.58 (0.39-0.83) *	0.52 (0.33-0.78) *	0.59 (0.34-0.94) *	0.53 (0.30-0.87) *
21-59 minutes	0.50 (0.32-0.74) *	0.50 (0.31-0.76) *	0.48 (0.25-0.80) *	0.44 (0.23-0.76) *
60+ minutes	0.50 (0.29-0.79) *	0.52 (0.29-0.87) *	0.50 (0.21-0.97)	0.51 (0.22-0.99)
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.67 (0.52-0.84) *	0.65 (0.49-0.84) *	0.68 (0.48-0.92) *	0.67 (0.48-0.92) *
21-59 minutes	0.49 (0.35-0.66) *	0.50 (0.35-0.69) *	0.49 (0.31-0.73) *	0.47 (0.30-0.71) *
60+ minutes	0.62 (0.45-0.84) *	0.65 (0.45-0.90) *	0.63 (0.39-0.96) *	0.58 (0.35-0.90) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.60 (0.47-0.74) *	0.58 (0.44-0.73) *	0.58 (0.42-0.78) *	0.57 (0.41-0.77) *

High ≥ mean	0.69 (0.48-0.96) *	0.82 (0.56-1.15)	0.87 (0.55-1.30)	0.85 (0.53-1.28)
Gym-based-strength exercises				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.56 (0.41-0.74) *	0.50 (0.35-0.69) *	0.53 (0.35-0.77) *	0.50 (0.32-0.73) *
High ≥ mean	0.48 (0.29-0.73) *	0.54 (0.32-0.85) *	0.53 (0.26-0.94) *	0.49 (0.23-0.89) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.50 (0.32-0.73) *	0.63 (0.50-0.77) *	0.62 (0.47-0.80) *	0.61 (0.46-0.79) *
High ≥ mean	0.49 (0.23-0.89) *	0.53 (0.36-0.75) *	0.56 (0.35-0.85) *	0.52 (0.31-0.80) *

Musculoskeletal Condition				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.54 (0.47-0.64) *	0.50 (0.41-0.61) *	0.53 (0.41-0.66) *	0.53 (0.42-0.67) *
21-59 minutes	0.56 (0.42-0.71) *	0.54 (0.40-0.72) *	0.63 (0.43-0.87) *	0.63 (0.44-0.88) *
60+ minutes	0.73 (0.55-0.99) *	0.68 (0.47-0.95) *	0.77 (0.49-1.14)	0.72 (0.45-1.09)
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.46 (0.34-0.59) *	0.51 (0.37-0.67) *	0.46 (0.30-0.65) *	0.46 (0.31-0.67) *
21-59 minutes	0.34 (0.24-0.47) *	0.34 (0.23-0.48) *	0.38 (0.24-0.57) *	0.36 (0.23-0.55) *
60+ minutes	0.31 (0.20-0.45) *	0.32 (0.20-0.50) *	0.32 (0.16-0.57) *	0.33 (0.16-0.58) *
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)

10-20 minutes	0.63 (0.53-0.73) *	0.59 (0.49-0.71) *	0.61 (0.48-0.76) *	0.61 (0.48-0.76) *
21-59 minutes	0.45 (0.36-0.55) *	0.45 (0.35-0.57) *	0.54 (0.40-0.70) *	0.53 (0.40-0.70) *
60+ minutes	0.48 (0.38-0.60) *	0.47 (0.36-0.61) *	0.48 (0.33-0.66) *	0.45 (0.31-0.64) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.54 (0.46-0.63) *	0.51 (0.42-0.61) *	0.54 (0.43-0.66) *	0.53 (0.43-0.66) *
High ≥ mean	0.67 (0.53-0.84) *	0.62 (0.47-0.81) *	0.73 (0.52-0.98) *	0.72 (0.51-0.97) *
Gym-based-strength exercises				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.43 (0.35-0.53) *	0.41 (0.32-0.58) *	0.44 (0.33-0.59) *	0.44 (0.32-0.58) *
High ≥ mean	0.26 (0.17-0.38) *	0.26 (0.16-0.40) *	0.29 (0.16-0.49) *	0.30 (0.16-0.50) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.57 (0.50-0.65) *	0.55 (0.48-0.64) *	0.58 (0.49-0.70) *	0.58 (0.48-0.70) *
High ≥ mean	0.43 (0.33-0.54) *	0.41 (0.31-0.53) *	0.46 (0.33-0.63) *	0.46 (0.32-0.63) *

Chronic Conditions		
Duration/session		
Own-bodyweight exercises	Model D [d] 1 condition	Model D [d] ≥2 conditions
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.70 (0.55-0.87) *	0.29 (0.18-0.44) *
21-59 minutes	0.84 (0.59-1.16)	0.30 (0.13-0.58) *
60+ minutes	0.66 (0.38-1.07)	0.16 (0.03-0.48) *

Gym-based-strength exercises		
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.63 (0.44-0.88) *	0.17 (0.06-0.36) *
21-59 minutes	0.62 (0.42-0.88) *	0.07 (0.01-0.23) *
60+ minutes	0.66 (0.38-1.05)	0.16 (0.03-0.48) *
Total-MSE		
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.73 (0.58-0.92) *	0.34 (0.22-0.51) *
21-59 minutes	0.62 (0.46-0.82) *	0.21 (0.10-0.36) *
60+ minutes	0.70 (0.50-0.95) *	0.09 (0.02-0.24) *
Volume/week (frequency x duration)		
Own-bodyweight exercises [e]		
None	1 (reference)	1 (reference)
Low < mean	0.68 (0.55-0.83) *	0.25 (0.16-0.38) *
High ≥ mean	0.89 (0.63-1.21)	0.35 (0.16-0.65) *
Gym-based-strength exercises		
None	1 (reference)	1 (reference)
Low < mean	0.56 (0.41-0.73) *	0.13 (0.06-0.26) *
High ≥ mean	0.84 (0.57-1.20)	0.12 (0.02-0.36) *
Total-MSE [e]		
None	1 (reference)	1 (reference)
Low < mean	0.67 (0.55-0.80) *	0.26 (0.17-0.37) *
High ≥ mean	0.76 (0.56-1.01) *	0.20 (0.08-0.38) *

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength

* Result is significant i.e., <0.05

[a] Unadjusted model (Model A)

[b] Model B - adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles)

[c] Model C - adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness)

[d] Model D adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic MVPA and weekly sedentary time

[e] mean value: own bodyweight 76.1 min/week, gym-based strength 99.4 min/week, total-MSE 107.6 min/week [low = below the mean, high = above the mean]

Appendix-D

Analysis of the relationship between muscle-strengthening exercise (duration/session) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two models combined (APRs; 95%CI).

Model D [d]	**Diabetes**	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Duration/session							
Own-bodyweight exercises							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.40 (0.25-0.59) *	0.54 (0.40-0.71) *	0.58 (0.40-0.79) *	0.53 (0.42-0.67) *	0.50 (0.36-0.68) *	0.70 (0.55-0.87) *	0.29 (0.18-0.44) *
21-59 minutes	0.36 (0.17-0.68) *	0.42 (0.24-0.67) *	0.85 (0.52-1.28)	0.63 (0.44-0.88) *	0.73 (0.46-1.10)	0.84 (0.59-1.16)	0.30 (0.13-0.58) *
60+ minutes	0.26 (0.06-0.66) *	0.37 (0.16-0.71) *	0.55 (0.24-1.08)	0.72 (0.45-1.09)	0.34 (0.12-0.73) *	0.66 (0.38-1.07)	0.16 (0.03-0.48) *
Gym-based-strength exercises							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.55 (0.30-0.92) *	0.58 (0.37-0.86) *	0.53 (0.30-0.87) *	0.46 (0.31-0.67) *	0.47 (0.28-0.75) *	0.63 (0.44-0.88) *	0.17 (0.06-0.36) *
21-59 minutes	0.31 (0.13-0.61) *	0.32 (0.17-0.54) *	0.44 (0.23-0.76) *	0.36 (0.23-0.55) *	0.39 (0.21-0.66) *	0.62 (0.42-0.88) *	0.07 (0.01-0.23) *
60+ minutes	0.49 (0.19-0.99)	0.19 (0.06-0.45) *	0.51 (0.22-0.99)	0.33 (0.16-0.58) *	0.68 (0.34-1.20)	0.66 (0.38-1.05)	0.16 (0.03-0.48) *
Total-MSE							

0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.47 (0.30-0.68) *	0.58 (0.43-0.76) *	0.67 (0.48-0.92) *	0.61 (0.48-0.76) *	0.57 (0.41-0.77) *	0.73 (0.58-0.92) *	0.34 (0.22-0.51) *
21-59 minutes	0.39 (0.23-0.62) *	0.40 (0.27-0.57) *	0.47 (0.30-0.71) *	0.53 (0.40-0.70) *	0.49 (0.32-0.70) *	0.62 (0.46-0.82) *	0.21 (0.10-0.36) *
60+ minutes	0.31 (0.15-0.57) *	0.27 (0.15-0.45) *	0.58 (0.35-0.90) *	0.45 (0.31-0.64) *	0.46 (0.27-0.72) *	0.70 (0.50-0.95) *	0.09 (0.02-0.24) *

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength

* Result is significant i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

Appendix-E

Analysis of the relationship between muscle-strengthening exercise (volume/week) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two models combined (APRs; 95%CI).

Model D [d]	**Diabetes**	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Volume/week (frequency x duration)							
Own-bodyweight exercises [e]							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.36 (0.24-0.53) *	0.45 (0.33-0.59) *	0.57 (0.41-0.77) *	0.53 (0.43-0.66) *	0.51 (0.37-0.67) *	0.68 (0.55-0.83) *	0.25 (0.16-0.38) *
High ≥ mean	0.39 (0.19-0.71) *	0.62 (0.39-0.91) *	0.85 (0.53-1.28)	0.72 (0.51-0.97) *	0.62 (0.38-0.96) *	0.89 (0.63-1.21)	0.35 (0.16-0.65) *
Gym-based-strength exercises [e]							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.46 (0.28-0.70) *	0.48 (0.33-0.66) *	0.50 (0.32-0.73) *	0.44 (0.32-0.58) *	0.38 (0.24-0.57) *	0.56 (0.41-0.73) *	0.13 (0.06-0.26) *
High ≥ mean	0.42 (0.18-0.82) *	0.22 (0.09-0.44) *	0.49 (0.23-0.89) *	0.30 (0.16-0.50) *	0.76 (0.44-1.20)	0.84 (0.57-1.20)	0.12 (0.02-0.36) *
Total-MSE [e]							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.40 (0.28-0.55) *	0.50 (0.39-0.63) *	0.61 (0.46-0.79) *	0.58 (0.48-0.70) *	0.48 (0.36-0.62) *	0.67 (0.55-0.80) *	0.26 (0.17-0.37) *

High ≥ mean	0.43 (0.24-0.71) *	0.30 (0.18-0.48) *	0.52 (0.31-0.80) *	0.46 (0.32-0.63) *	0.65 (0.43-0.93) *	0.76 (0.56-1.01) *	0.20 (0.08-0.38) *

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength

* Result is significant i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic- MVPA and weekly sedentary time

[e] Mean value: own bodyweight 76.1min/week, gym-based strength 99.4 min/week, total-MSE 107.5 min/week [low = below the mean, high = above the mean]

Supplementary Table 1.1: Age stratified muscle-strengthening exercise behaviour characteristics (exposure variable) of participants included in the analysis

Total sample of 2012 and 2016 Health Survey for England (n = 16,301)

Total	**Total**	**16-54 years**	**55+ years**
	% (n)	**% (n)**	**% (n)**
Muscle- strengthening exercise – Session duration			
Own-bodyweight (minutes/session)			
0 minutes	86.2 (14,057)	82.1 (7,721)	91.8 (6,336)
10-20 minutes	8.6 (1,406)	11.1 (1,035)	5.4 (371)
21-59 minutes	3.3 (533)	4.4 (415)	1.7 (118)
60+ minutes	1.9 (305)	2.5 (231)	1.1 (74)
Gym-based-strength (minutes/session)			
0 minutes	90.5 (14,752)	86.4 (8,126)	96.0 (6,626)
10-20 minutes	3.7 (603)	4.9 (459)	2.1 (144)
21-59 minutes	3.4 (558)	5.0 (473)	1.2 (85)
60+ minutes	2.4 (388)	3.7 (344)	0.6 (44)
Total-MSE (minutes/session)			
0 minutes	81.5 (13,285)	75.6 (7,105)	89.6 (6,180)

10-20 minutes	7.8 (1,278)	9.4 (886)	5.7 (392)
21-59 minutes	6.0 (982)	8.4 (789)	2.8 (193)
60+ minutes	4.6 (756)	6.6 (622)	1.9 (134)
Muscle- strengthening exercise – Weekly volume			
Own-bodyweight (minutes x frequency)			
None	86.2 (14,057)	82.1 (7,721)	91.8 (6,336)
Low < mean	10.3 (1,672)	13.5 (1,272)	5.8 (400)
High ≥ mean	3.5 (572)	4.4 (409)	2.4 (163)
Gym-based-strength (minutes x frequency)			
None	90.5 (14,757)	86.5 (8,129)	96.1 (6,627)
Low < mean	6.5 (1,062)	9.0 (842)	3.2 (220)
High ≥ mean	3.0 (482)	4.6 (430)	0.8 (52)
Total-MSE (minutes x frequency)			
None	81.5 (13,287)	75.6 (7,107)	89.6 (6,180)
Low < mean	13.4 (2,177)	17.1 (1,610)	8.2 (567)
High ≥ mean	5.1 (837)	7.3 (685)	2.2 (152)

MSE: muscle-strengthening exercise

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

Mean values: own-bodyweight 76.1 min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week

Appendix-F– stratified by age

Analysis of the relationship between muscle-strengthening exercise (duration/session) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise (total-MSE) combined (APRs; 95%CI).

	Diabetes	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Duration/session – total-MSE							
16-54 years							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.19 (0.05-0.49) *	0.61 (0.31-1.08)	0.77 (0.48-1.16)	0.51 (0.33-0.74) *	0.51 (0.33-0.74) *	0.71 (0.51-0.95) *	0.12 (0.03-0.32) *
21-59 minutes	0.47 (0.20-0.93) *	0.54 (0.26-1.00)	0.56 (0.32-0.92) *	0.44 (0.27-0.67) *	0.52 (0.33-0.77) *	0.66 (0.46-0.92) *	0.34 (0.14-0.66) *
60+ minutes	0.56 (0.22-1.16)	0.08 (0.00-0.37) *	0.57 (0.29-1.00)	0.49 (0.28-0.77) *	0.51 (0.30-0.81) *	0.67 (0.44-0.97) *	0.13 (0.02-0.41) *
55+ years							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.73 (0.46-1.10)	0.73 (0.53-1.00) *	0.66 (0.39-1.04)	0.82 (0.61-1.07)	0.70 (0.41-1.11)	0.90 (0.62-1.25)	0.66 (0.40-1.02) *
21-59 minutes	0.62 (0.30-1.13)	0.69 (0.41-1.06)	0.48 (0.19-0.99)	1.03 (0.71-1.44)	0.33 (0.10-0.78) *	0.70 (0.41-1.12)	0.19 (0.05-0.50) *
60+ minutes	0.33 (0.08-0.86)	0.73 (0.39-1.23)	0.90 (0.38-1.76)	0.77 (0.44-1.23)	0.16 (0.01-0.70)	1.15 (0.64-1.87)	0.16 (0.01-0.72)

MSE = muscle-strengthening exercise, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

[*] Result is significant i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

Appendix-G – stratified by age

Analysis of the relationship between muscle-strengthening exercise (volume/week) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise (total-MSE) combined (APRs; 95%CI).

	Diabetes	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Volume/week (frequency x duration)							
16-54 years							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.33 (0.16-0.61) *	0.60 (0.36-0.93) *	0.62 (0.42-0.88) *	0.51 (0.37-0.69) *	0.44 (0.31-0.60) *	0.67 (0.52-0.85) *	0.18 (0.08-0.35) *
High ≥ mean	0.51 (0.20-1.06)	0.08 (0.00-0.34) *	0.72 (0.41-1.16)	0.39 (0.22-0.64) *	0.70 (0.45-1.04)	0.72 (0.48-1.02)	0.25 (0.08-0.58) *
55+ years							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.61 (0.40-0.89) *	0.72 (0.54-0.93) *	0.74 (0.49-1.08)	0.86 (0.68-1.08)	0.55 (0.33-0.85) *	0.80 (0.59-1.07)	0.47 (0.29-0.72) *
High ≥ mean	0.72 (0.33-1.35)	0.74 (0.43-1.19)	0.31 (0.08-0.82) *	0.88 (0.55-1.31)	0.36 (0.09-0.93)	1.16 (0.70-1.79)	0.36 (0.09-0.93)

MSE = muscle-strengthening exercise, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

* Represents significance i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

[e] Mean value: own-bodyweight 76.1min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week [low = below the mean, high = above the mean]

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Competing interests

The authors declare that they have no competing interests.

Confirmation of Ethical Compliance

The data used in this research has historic ethics approval from the East Midlands Nottingham 2 Research Ethics Committee (Reference no 15/EM/0254), and the Oxford A Research Ethics Committee (Reference no 10/H0604/56).

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