BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-011843
Article Type:	Research
Date Submitted by the Author:	10-Mar-2016
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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Sports and exercise medicine, Research methods, Public health
Keywords:	Physical activity, UK Biobank, BMI, Body fat percentage

Physically active adults have lower body fat percentage, after adjusting for BMI: a cross-sectional analysis of UK Biobank

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Abstract

Objectives: The objective of this study was to examine if physically active adults have less body fat after taking BMI into account.

Design: A cross-sectional analysis of participants recruited into UK Biobank in 2006-2010.

Setting: UK Biobank assessment centres throughout the UK.

Participants: 119,230 men and 140,578 women aged 40-69 years, with complete physical activity information, and without a self-reported long-term illness, disability or infirmity.

Exposures: Physical activity measured as excess MET-hours per week, estimated from a combination of walking, and moderate and vigorous physical activity. BMI from measured height and weight.

Main outcome measure: Body fat percentage estimated from bio-impedance.

Results: BMI and body fat percentage were highly correlated (r=0.85 in women; r=0.79 in men), and both were inversely associated with physical activity. Compared to <5 excess metabolic equivalent (MET)-hours per week at baseline, ≥100 excess MET-hours per week was associated with a 1.1 kg/m^2 lower BMI (27.1 versus 28.2 kg/m^2) and 2.8 percentage points lower body fat (23.4% versus 26.3%) in men, and 2.2 kg/m^2 lower BMI (25.6 versus 27.7 kg/m^2) and 4.0 percentage points lower body fat (33.9% versus 37.9%) in women. For a given BMI, greater physical activity was associated with lower average body fat percentage (for a BMI of 22.5-24.99 kg/m^2: 2.0 (95% CI: 1.8 to 2.2) percentage points lower body fat in men, and 1.8 (95% CI: 1.6 to 2.0) percentage points lower body fat in women, comparing ≥100 excess MET-hours per week to <5 excess MET-hours per week).

Conclusions: Physical activity was inversely associated with BMI and body fat percentage. For people with the same BMI, those who were more active had a lower body fat percentage.

Strengths and limitations of this study

- This study of older adults, drawn from the general population, is very large (n = 259,808) and height and weight (for the calculation of BMI) were measured by trained staff using standardised techniques.
- Body fat percentage (estimated via bio-impedance) was available for virtually all participants.
- Physical activity was self-reported and therefore there will be some measurement error associated with this variable.
- The study is cross-sectional and therefore we cannot infer cause and effect.

Introduction

Body mass index (BMI) is a simple index calculated from height and weight, and is usually used as a proxy for body fatness in large epidemiological studies. Correlations between BMI and more direct measures of body fatness are generally strong (r > 0.70) (1, 2).

Observational studies have shown that people who do comparatively more physical activity have a lower BMI than less active people (3, 4). Few large epidemiological studies have directly estimated body fatness, and it is of interest to examine whether more comprehensive measures of body fatness provide additional information above and beyond that which is captured by BMI. Previous studies each of approximately 500 young adults have found that, for a given BMI, athletes have a lower body fat percentage than non-athletes (5, 6); however it is unclear whether in the general population, including older adults, those who do more physical activity have a lower body fat percentage than those who do minimal physical activity, after taking into account BMI.

UK Biobank is a population-based cohort of 500,000 UK men and women, aged 40-69 years at recruitment. Body mass index and body fat percentage were measured at recruitment for virtually all participants. For this analysis of data from UK Biobank we aimed firstly to describe the associations of physical activity with BMI and body fat percentage, and secondly to determine whether physical activity is associated with body fat percentage, independently of BMI. We also examined whether the associations were influenced by important lifestyle factors.

METHODS

Subjects

UK Biobank is a prospective cohort of approximately 500,000 people aged 40-69 years, recruited in 2006-2010 in the UK (7). People aged 40-69 years who lived within reasonable travelling distance of 22 assessment centres were identified from National Health Service patient registers and invited to participate in UK Biobank by attending an assessment centre. Permission for access to patient records for recruitment was approved by the National Information Governance Board for Health and Social Care in England and Wales, and the Community Health Index Advisory Group in Scotland. A sub-sample of approximately 20,000 participants completed a full repeat of the assessment centre visit between August 2012 and June 2013, approximately 5 years after recruitment (8). UK Biobank has ethical approval from the North West Multi-centre Research Ethics Committee. The UK Biobank protocol is available online (http://www.ukbiobank.ac.uk/wp-content/uploads/2011/11/UK-Biobank-Protocol.pdf). The touchscreen questionnaire and other resources are also available on the UK Biobank website (http://www.ukbiobank.ac.uk/resources/).

Anthropometric measurements

At the UK Biobank assessment centres, a touchscreen questionnaire was used to collect information on socio-demographic characteristics and lifestyle exposures. Socks and shoes were removed and height was measured using the Seca 202 height measure (Seca, Hamburg, Germany). Weight and estimated percentage fat were measured with the Tanita BC418ma bio-impedance device (Tanita, Tokyo, Japan).

Physical activity assessment

Questions on the touchscreen about walking, moderate physical activity, and vigorous physical activity, which were similar to those used in the short form of the International Physical Activity Questionnaire (9), were used to estimate excess metabolic equivalents (MET)-hours per week of physical activity during work and leisure time. For each of the three activity categories (walking, moderate physical activity, and vigorous physical activity) participants were asked how many days in a typical week they did each of the activities for 10 minutes or more (for walking: touchscreen question number WP1, UK Biobank variable n_864_0_0; for moderate physical activity: touchscreen question number WP2, UK Biobank variable n_884_0_0; for vigorous physical activity: touchscreen question number WP3, UK Biobank variable n_904_0_0). For each category, participants who entered one or more days were then asked how many minutes they spent doing those activities on a typical day (for walking: WP1A, n_874_0_0; for moderate physical activity: WP2A, n_894_0_0; for vigorous physical activity: WP3A, n_914_0_0). For each activity category, the number of reported days was multiplied by the number of reported minutes on a typical day to generate duration of activity in minutes per week.

Activity on a typical day of less than 10 minutes was recoded to 0 for any of the three categories of activity. For each of the three categories of activity, values of more than 1260 minutes per week (equivalent to an average of 3 hours per day) were truncated at 1260 (9).

Total MET values for each category from the International Physical Activity Questionnaire short form were: 3.3 for walking, 4.0 for moderate physical activity, and 8.0 for vigorous physical activity (9). We report excess METs, which are calculated by subtracting 1 MET from the value for each activity, and represent the energy expenditure above that of an inactive person (10). Excess MET values were therefore 2.3 for walking, 3.0 for moderate physical activity, and 7.0 for vigorous physical activity. Excess MET-hours per week were calculated by multiplying the excess MET value for each activity by the duration of activity in hours per week (9).

Exclusions

The UK Biobank dataset used for this analysis included 502,640 participants. Participants were excluded from this analysis if they selected 'Prefer not to answer' or 'Do not know' to any of the possible six questions on physical activity (WP1, WP1A, WP2, WP2A, WP3, WP3A) (n = 66,625). Participants were also excluded from this analysis if they responded to the question: "Do you have a long-term illness, disability or infirmity?" with 'Yes' (n = 159,941), 'Prefer not to answer' (n = 1,052) or 'Do not know' (n = 11,391), or if they had a missing value for this variable (n = 919) (touchscreen question number H4, UK Biobank variable n_2188_0_0). In addition, the questions used in the pilot study on the duration of physical activity differed from those in the main study, and participants who answered the pilot version of these questions were excluded (n = 2,253). Based on the International Physical Activity Questionnaire recommendations for data cleaning and processing (9), participants were also excluded from the analysis if the sum of walking, moderate physical activity, and vigorous physical activity was greater than 112 hours per week (n = 651), leaving a total of 259,808 participants in the present study.

Statistics

STATA version 14.0 (Stata Corp LP, College Station, TX) was used for all statistical analyses. All analyses were done for men and women separately. Participant characteristics were described by level of physical activity (low, < 10.0; moderate, 10.0-49.9; high, ≥ 50 excess MET-hours per week). Pearson's correlation coefficients between BMI and body fat percentage were calculated. Multiple linear regression was used to calculate the mean body fat % in single units of BMI (e.g. 17.00-17.99, 18.00-18.99, 19.00-19.99 kg/m^2, etc), adjusted for age (5 year categories: < 45 years, 45-49.99 years, 50-54.99 years, 55-59.99 years, 60-64.99 years, ≥ 65.00 years). Groups with 200 or more participants are shown in the Figure. Multiple linear regression was also used to calculate mean BMI and body fat percentage in categories of excess MET-hours per week (< 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hours per week), adjusted for age (5 year categories, as above). For the final analysis, we used multiple linear regression to examine the association between physical activity (in excess MET-hours per week: < 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100) and body fat percentage (continuous variable). Body mass index (in 2.5 unit categories, e.g. < 18.50, 18.50-19.99, 20.00-22.49, 22.50-24.99, 25.00-27.49…,42.50-44.99, ≥ 45.00 kg/m^2, etc) and age (5 year categories) were included as covariates. We included a product term of excess MET-hours per week (categories, as above) and BMI (in 2.5 unit categories as above) in the model to calculate mean body fat percentage in categories of physical activity within strata of BMI. In additional sensitivity analyses, we adjusted for reported intakes of fruit and vegetables (< 3.00 servings/week, 3.00-3.99, 4.00-4.99, 5.00-5.99, ≥ 6.00 servings/week, unknown), and red and processed meat (< 2.00 servings/week, 2.00-2.99, 3.00-3.99, 4.00-4.99, ≥ 5.00 servings/week, unknown). We also restricted the analysis to those with a university or college degree, and separately, to those that do not have a job that usually or always involves standing or walking or manual work.

We also examined mean BMI and body fat percentage in 5 year age categories. For each age decade separately (i.e. participants < 50 years, 50-59 years, and ≥ 60 years) linear regression was used to calculate mean body fat percentage in single units of BMI, and to calculate mean BMI and body fat percentage in each category of physical activity (< 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hours per week).

To explore the repeatability of self-reported physical activity, including effects of measurement error and possible changes in activity over time, we used a sub-sample of 10,225 UK Biobank participants who were eligible for the current study and who completed a repeat assessment visit approximately 5 years after recruitment (Supplementary Tables S1 and S2). For these participants, we calculated excess MET-hours per week from their answers to the touchscreen questionnaire completed at the repeat assessment centre visit, as described above. Then for each category of excess MET-hours per week defined at baseline, we calculated both the mean excess MET-hours per week at their baseline visit (to assess comparability of the sub-sample to the full cohort) and the mean excess MET-hours per week at the repeat visit (to assess measurement error in reporting physical activity and change over time). The sub-sample of participants who completed a repeat assessment centre visit approximately 5 years after recruitment was similar at baseline to the full cohort with regard to reported physical activity. However, at the repeat assessment, for participants in the highest category of physical activity defined at baseline (≥ 100 excess MET-hours per week), the mean excess MET-hours per week was much lower than at baseline (80 compared to 130 for both men and women). For the lowest category of physical activity defined at baseline, the mean excess MET-hours per week was somewhat higher at the repeat assessment than at baseline (12 compared to 2.6 for both men and women). Overall, this represents regression to the mean of almost 50% (calculated from the ratio of the range of mean values at the repeat assessment to the range of mean values at baseline). The Pearson's correlation coefficients between recruitment and repeat measurements of BMI and body fat percentage in the sub-sample of participants who completed a repeat assessment centre visit were 0.92 for both BMI and body fat percentage.

All p values were two-sided and $P < 0.05$ was considered statistically significant.

RESULTS

Participant flow is shown in Figure 1. Participants who had a high level of physical activity were older, had a lower BMI, a lower body fat percentage, and a higher intake of fruit and vegetables than participants with a low level of physical activity (Table 1 and Table 2). They were also less likely to have a college or university degree, and much more likely to have a standing or manual job than those with a moderate or low level of physical activity. Participants with a moderate activity level were the least likely to be current smokers.

Body fat percentage was positively related to BMI (Figure 2). The correlation between BMI and body fat percentage was 0.85 in women, and 0.79 in men. At the same BMI, women had a much higher body fat percentage than men; for example, women with a BMI of 30.00-30.99 kg/m^2 had on average 41% body fat, whereas men with the same BMI had on average 28% body fat.

Body fat percentage and BMI were inversely related to physical activity (Figure 3). Men who did < 5 excess MET-hours of physical activity per week had, on average, a BMI of 28.2 kg/m^2 (95% Confidence Interval (CI): 28.2 to 28.3 kg/m^2) and 26.3% (95% CI: 26.2 to 26.4 kg/m^2) body fat. Men who did ≥100 excess MET-hours per week of physical activity per week had, on average, a BMI of 27.1 kg/m^2 (95% CI: 27.0 to 27.2 kg/m^2) and 23.4% (95% CI: 23.3 to 23.5%) body fat. Women who did < 5 excess MET-hours per week of physical activity per week had, on average, a BMI of 27.7 kg/m^2 (95% CI: 27.7 to 27.8 kg/m^2) and 37.9% (95% CI: 37.8 to 38.0%) body fat. Women who did ≥ 100 excess MET-hours per week of physical activity per week had, on average, a BMI of 25.6 kg/m^2 (95% CI: 25.5 to 25.7 kg/m^2) and a 33.9% (95% CI: 33.7 to 34.0%) body fat. For both men and women, as shown by the r^2 values, age and physical activity explained more of the variation in body fat

percentage than the variation in BMI in this study population; however, age and physical activity only explained a small proportion of the variation in both BMI and body fat percentage in this study population, with all r^2 values less than 0.06 (Figure 3).

Overall, in males, those doing ≥ 100 or more excess MET-hours per week compared with < 5 excess MET-hours per week had a 1.7 (95% CI: 1.6 to 1.7) percentage points lower body fat percentage, on average, after adjustment for BMI and age; in females it was on average 1.5 (95% CI: 1.4 to 1.6) percentage points lower. For both men and women, within each stratum of BMI, a higher physical activity level was associated with a lower body fat percentage, and the difference in body fat percentage between physical activity categories appeared to be slightly larger at lower BMIs (p for interaction using likelihood ratio test < 0.001, for both sexes) (Figure 4, Supplementary Tables S3 and S4). For a BMI of 22.5-24.99 kg/m^2, ≥ 100 excess MET-hours per week vs < 5 excess MET-hours per week was associated with 2.0 (95% CI: 1.8 to 2.2) percentage points lower body fat in men and 1.9 (95% CI: 1.6 to 2.0) percentage points lower body fat in women. For both men and women, within each stratum of BMI, the mean BMI was very similar across the categories of physical activity.

When we further adjusted for reported intakes of fruit and vegetables, and red and processed meats, or restricted the analysis to those who did not have an active job or those who had a university or college degree, the results were not materially altered. Comparing those doing ≥ 100 excess MET-hours per week to those doing < 5 excess MET-hours per week, body fat percentage was, on average 1.6 (95% CI: 1.5 to 1.7) percentage points lower for men and 1.4 (95% CI: 1.3 to 1.5) percentage points lower for women after adjustment for diet quality; 1.7 (95% CI: 1.6 to 1.9) percentage points lower for men and 1.6 (95% CI: 1.4 to 1.8) percentage points lower for women when restricting analyses to those who had a university or college

degree; and 1.6 (95% CI: 1.5 to 1.7) percentage points lower for men and 1.4 (95% CI: 1.3 to 1.5) percentage points lower for women when we restricted analyses to those who did not have a standing or manual job.

In men, the mean BMI was similar across 5-year age categories however the mean body fat percentage was higher in older age groups. In women, the mean BMI by 5-year age categories was slightly higher in older age groups, and the mean body fat percentage was also higher in older age groups (Supplementary Table S5). The association between BMI and body fat percentage was similar in each age decade (Supplementary Figures S1, S2, and S3). The differences in BMI between the extreme categories of physical activity were slightly larger and the differences in body fat percentage were slightly smaller with older age (Supplementary Figures S4, S5 and S6).

DISCUSSION

In this large sample of middle-aged British men and women, more physical activity was associated with both a lower BMI and a lower body fat percentage, although even men and women who did the most physical activity were, on average, overweight. More physical activity was also associated with a lower body fat percentage within each category of BMI, with an average 1-2 percentage points lower body fat in the most active, compared to the least active individuals. Most of the difference in body fat percentage with physical activity was between the very low and moderately-high levels of physical activity (<5 and 35-49.9 excess MET-hours per week, respectively); there was relatively little difference in body fat percentage between moderately-high and very high levels of physical activity (35-49.9 and ≥100 excess MET-hours per week, respectively).

The current study is large, and height and weight were measured by trained staff using standardised techniques. We examined whether important lifestyle factors (diet quality, education, and job type) which varied by physical activity level might modify the associations between physical activity, BMI and body fat percentage. In each of these sensitivity analyses, the results were essentially unchanged, although because this is an observational study we cannot rule out confounding by other factors. A limitation of the study is that physical activity was self-reported. Analysis of the sub-sample who had a repeat measurement of physical activity approximately 5 years after baseline indicates approximately 50% regression to the mean, which represents both the error in reporting physical activity and true changes in physical activity over time. The likely consequence of regression to the mean in physical activity levels over time is bias of associations towards the null, so that the true association between physical activity and body composition measures is likely to be stronger than that observed in this study. The study is cross-sectional, and therefore we can only show associations between reported physical activity and contemporaneous body composition. We cannot infer cause and effect: lower levels of physical activity may lead to greater adiposity, but it is also possible that increased adiposity leads to less physical activity.

Small studies (n~500) in young adults have shown that, for a given BMI, athletes have a lower body fat percentage than non-athletes (5, 6). These findings are, however, of limited relevance to older adults in the general population, who experience the highest burden of obesity-related disease. An analysis of 466,605 participants in the China Kadoorie Biobank, aged 30-79 years, found relatively weak associations between physical activity and either BMI or body fat percentage: a difference of approximately 100 total MET-hours per week was associated with 0.15 kg/m^2 lower BMI, and 0.48 percentage points lower body fat (11). Participants in China Kadoorie Biobank differed from those in UK Biobank in ethnicity and lifestyle, and also had a lower average BMI (23.4 (SD 3.2) kg/m^2 in men; 23.8 (SD 3.4) kg/m^2 in women). Their physical activity levels were comparable to the middle to upper range of physical activity of UK Biobank participants, and in this range we also saw only a small difference in body fat percentage.

Variation in BMI in the general population is largely due to differences in body fatness, but by definition it incorporates both adipose and lean body mass, and it is therefore difficult to disentangle the roles of adipose and lean mass in associations of BMI with health outcomes. For example, a higher BMI is an established risk factor for post-menopausal breast cancer, and probably increases risk through higher circulating sex hormones produced by the enzyme aromatase in the adipose tissue from precursor androgens (12). Several cohort studies have also shown that more physical activity is associated with a reduced risk of post-menopausal breast cancer, even after adjustment for BMI, and this finding is often taken as evidence that physical activity is independent of adiposity as a risk factor for post-menopausal breast cancer (13). Our results suggest, however, that adjustment for BMI may not have fully controlled for adiposity in these analyses.

In conclusion, in this sample of middle-aged British adults who were free from self-reported long-standing illness, men and women who reported doing the most physical activity had a lower BMI and a lower body fat percentage than those who reported doing the least physical activity. We also report new evidence that, for a given BMI, men and women who reported doing more physical activity had a lower body fat percentage; the greatest difference was observed between low and moderate levels of physical activity. BMI incorporates both adipose and lean mass, but is most strongly related to adiposity, and consequently is associated with morbidity and mortality from a wide range of diseases. However, to disentangle the possible effects of physical activity and adiposity on disease risk, future research should focus on more specific measures of adiposity.

Competing interests: All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

Contributorship: KEB and TJK conceived the research, KEB performed the statistical analyses; BJC contributed to the statistical methodology; MEGA contributed to generation of the physical activity variables. KEB, WG, BJC, MEGA, and TJK interpreted the data, drafted and reviewed the article for important intellectual content, KEB has primary responsibility for the final content. All authors read and approved the final manuscript. KEB is the guarantor for the study. This research has been conducted using the UK Biobank Resource.

Ethics approval: UK Biobank has ethical approval from the North West Multi-centre Research Ethics Committee. Participants gave informed consent on the touchscreen before taking part.

Funding: The authors are supported by Girdlers' New Zealand Health Research Council Fellowship (KEB), Cancer Research UK (TJK; C8221/A19170 and 570/A16491), the BHF Centre of Research Excellence, Oxford (BJC; BHF no. RE/13/1/30181), the UK Medical Research Council (MEGA, and TJK; MR/M012190/1), and the Clarendon Fund and US-UK Fulbright Commission (WG). The funders did not influence the conduct of the study, analysis or interpretation of the data, the writing of this report, or the decision to publish. The authors had full access to all the data in the study, can take responsibility for the integrity of the data, and the accuracy of the data analysis.

Data sharing: UK Biobank is an open access resource. Bona fide researchers can apply to use the UK Biobank dataset by registering and applying at http://www.ukbiobank.ac.uk/register-apply/. Statistical code for used for this manuscript is available to other researchers on request by emailing Kathryn Bradbury (kathryn.bradbury@ceu.ox.ac.uk).

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Table1 Characteristics of men participating in UK Biobank by physical activity

	Low activity < 10 excess MET-hours/wk[1] *n* = 26,405	Moderate activity 10-49.9 excess MET-hours/wk[1] *n* = 63,022	High activity ≥ 50 excess MET-hours/wk[1] *n* = 29,803	All men *n* = 119,230
Age (years)				
Mean (SD)	55.3 (8.0)	55.7 (8.4)	56.0 (8.4)	55.7 (8.3)
White ethnicity[a]	24,741 (93.7)	59,842 (95.0)	28,468 (95.5)	113,051 (94.8)
Socioeconomic status[b]				
Upper fifth	6,274 (23.8)	14,701 (23.4)	5,867 (19.7)	26,842 (22.5)
Qualifications[c]				
College or University degree/vocational qualification	18,878 (71.5)	45,453 (72.2)	17,731 (59.5)	82,062 (68.8)
BMI (kg/m^2)[d]				
Mean (SD)	28.0 (4.2)	27.1 (3.7)	27.1 (3.6)	27.3 (3.8)
< 20.00	238 (0.9)	559 (0.9)	289 (1.0)	1,086 (0.9)
20.00-24.99	5,849 (22.2)	17,425 (27.7)	8,326 (28.0)	31,600 (26.6)

25.00-29.99	13,220 (50.2)	32,745 (52.1)	15,403 (51.8)	61,368 (51.6)
≥ 30.00-34.99	7,015 (26.7)	12,135 (19.3)	5,699 (19.2)	24,849 (20.9)
Body fat (%)[e]				
Mean (SD)	25.8 (5.5)	24.2 (5.4)	23.6 (5.5)	24.4 (5.5)
< 15.00	761 (2.9)	3,062 (4.9)	1,945 (6.6)	5,768 (4.9)
15.00-19.99	2,810 (10.8)	9,714 (15.6)	5,148 (17.5)	17,672 (15.0)
20.00-24.99	7,714 (29.6)	21,023 (33.7)	10,080 (34.3)	38,817 (32.9)
25.00-29.99	9,194 (35.2)	19,816 (31.8)	8,686 (29.5)	37,696 (32.0)
≥ 30.00	5,629 (21.6)	8,703 (14.0)	3,558 (12.1)	17,890 (15.2)
Height (m)[f]				
< 1.70	3,902 (14.8)	9,251 (14.7)	5,467 (18.4)	18,620 (15.7)
1.70 - 1.74	6,250 (23.8)	15,301 (24.4)	7,917 (26.6)	29,468 (24.8)
1.75 - 1.79	7,738 (29.4)	18,182 (28.9)	8,246 (27.8)	34,166 (28.7)
1.80 - 1.84	5,308 (20.2)	12,992 (20.7)	5,408 (18.2)	23,708 (19.9)
≥ 1.85	3,115 (11.8)	7,120 (11.3)	2,682 (9.0)	12,917 (10.9)
Mean (SD) excess MET-hours per week[g]	5.1 (2.9)	25.8 (11.0)	92.9 (43.3)	38.0 (40.1)
Standing or walking job[h]	2,524 (12.7)	9,766 (23.1)	12,961 (65.4)	25,251 (30.8)

Manual job[i]	561 (2.8)	3,214 (7.6)	8,145 (41.1)	11,920 (14.6)
Smoking status[1j]				
Never	14,269 (54.0)	34,209 (54.3)	15,101 (50.7)	63,579 (53.3)
Previous	8,866 (33.6)	22,438 (35.6)	10,936 (36.7)	42,240 (35.4)
Current	3,215 (12.2)	6,252 (9.9)	3,680 (12.4)	13,147 (11.0)
Alcohol consumption[k]				
Three or more times a week	14,391 (54.5)	36,542 (58.0)	15,477 (52.0)	66,410 (55.8)
Fruit and vegetable consumption[l]				
< 3.00 servings per day	8,754 (33.2)	14,052 (22.3)	5,966 (20.0)	28,772 (24.1)
3.00-3.99 servings per day	6,031 (22.8)	13,370 (21.2)	5,204 (17.5)	24,605 (20.6)
4.00-4.99 servings per day	4,619 (17.5)	12,622 (20.0)	5,485 (18.4)	22,726 (19.1)
5.00-5.99 servings per day	2,926 (11.1)	8,930 (14.2)	4,389 (14.7)	16,245 (13.6)
≥ 6.00 servings per day	3,798 (14.4)	13,559 (21.5)	8,405 (28.2)	25,762 (21.6)
Total red and processed meat consumption[m]				
< 2.00 times per week	2,120 (8.0)	5,838 (9.3)	2,956 (9.9)	10,914 (9.2)
2.00-2.99 times a week	6,291 (23.8)	16,042 (25.5)	7,170 (24.1)	29,503 (24.7)
3.00-3.99 times a week	3,927 (14.9)	9,323 (14.8)	4,186 (14.1)	17,436 (14.6)

4.00-4.99 times a week	4,866 (18.4)	10,990 (17.4)	5,069 (17.0)	20,925 (17.6)
≥ 5.00 times a week	9,042 (34.2)	20,523 (32.6)	10,229 (34.3)	39,794 (33.4)

Values are number (%) unless otherwise stated

Number of participants with missing data (the total number participants who have missing data, or who reported 'do not know' or 'prefer not to answer') for each characteristic is as follows: 0 for age, 377 for ethnicity, 159 for socioeconomic status, 705 for qualifications, 327 for BMI, 1,367 for body fat %, 351 for height, 0 for excess MET-hours/wk, 57 for standing or walking job, 38 for manual job, 264 for smoking status, 35 for alcohol consumption, 1,120 for fruit and vegetable consumption, 658 for total red and processed meat consumption

[a]Participants who reported their ethnicity as 'White', 'British', 'Irish', or 'Any other white background'

[b]We generated quintiles of socioeconmic status based on the Townsend deprivation index for the whole cohort (UK Biobank variable n_189_0_0)

[c]Vocational qualifications defined as other professional qualification (eg: nursing or teaching)/ National Vocational Qualification or Higher National Diploma or Higher National Certificate) (touchscreen question number D12, UK Biobank variable n_6138_0_0)

[d]We preferentially used BMI derived from height and weight measured during the impedance measurement (UK Biobank variable n_23104_0_0_), but if missing used the body size measures (UK Biobank variable n_21001_0_0); both of these are direct measures of height and weight made on the same day at the assessment centre

[e]Body fat % (UK Biobank variable n_23099_0_0)

[f]Standing height (UK Biobank variable n_50_0_0)

[g]Excess MET-hours/wk estimated from the combination of reported walking, moderate and vigorous physical activity (for details see methods text)

[h]Participants who reported their work 'usually' or 'always' involved walking or standing for most of the time (touchscreen question number D9B, UK Biobank variable n_806_0_0)

[i]Participants who reported their work 'usually' or 'always' involved heavy manual or physical work for most of the time (touchscreen question number D9C, UK Biobank variable n_816_0_0)

[j]Smoking status (UK Biobank variable n_20116_0_0)

[k]Participants who reported consuming alcohol three to four times per week or daily or almost daily (touchscreen question number A1, UK Biobank variable n_1558_0_0)

[l]Total fruit and vegetable consumption is the sum of fresh fruit intake (touchscreen question number DT3, UK Biobank variable n_1309_0_0), cooked vegetable intake (touchscreen question numbers DT1, UK Biobank variable n_1289_0_0) and raw vegetable intake (touchscreen question number DT1, and UK Biobank variable n_1299_0_0). To sum the frequencies, ‘Less than one’ was coded as 0.5, and we coded 1 piece of fresh fruit as a serving and 2 tablespoons of vegetables as a serving.

[m]Total red and processed meat consumption is the sum of processed meat (touchscreen question number DT8 and UK Biobank variable n_1349_0_0), beef (touchscreen question number DT7 and UK Biobank variable n_1369_0_0), lamb/mutton (touchscreen question number DT7A and UK Biobank variable n_1379_0_0) , and pork (touchscreen question number DT7B and UK Biobank variable n_1389) intake. To sum the frequencies, we used the following coding: ‘Never’ = 0, ‘Less than once a week’ = 0.5, ‘Once a week’ = 1, ‘2-4 times a week’ = 3, ‘5-6 times a week’ = 5.5, ‘Once or more daily’ = 7.

Table 2 Characteristics of women participating in UK Biobank by physical activity

	Low activity < 10 excess MET-hours/wk[1] n = 31,931	Moderate activity 10-49.9 excess MET-hours/wk[1] n = 78,171	High activity ≥ 50 excess MET-hours/wk[1] n = 30,476	All women n = 140,578
Age (years)				
Mean (SD)	54.6 (7.8)	55.2 (8.1)	56.2 (8.1)	55.3 (8.1)
White ethnicity[a]	30,164 (94.5)	74,471 (95.3)	29,088 (95.5)	133,723 (95.1)
Socioeconomic status[b]				
Upper fifth	6,956 (21.8)	17,177 (22.0)	6,407 (21.0)	30,540 (21.8)
Qualifications[c]				
College or University degree/vocational qualification	19,320 (60.5)	49,219 (62.9)	17,826 (58.5)	86,365 (61.5)
BMI (kg/m^2)[d]				
Mean (SD)	27.2 (5.1)	26.0 (4.4)	25.7 (4.2)	26.2 (4.6)
< 20.00	954 (3.0)	2,838 (3.6)	1,270 (4.2)	5,062 (3.6)

20.00-24.99	10,930 (34.3)	33,256 (42.7)	13,749 (45.2)	57,935 (41.3)
25.00-29.99	12,037 (37.8)	29,041 (37.2)	11,062 (36.4)	52,140 (37.2)
≥ 30.00-34.99	7,930 (24.9)	12,839 (16.5)	4,334 (14.3)	25,103 (17.9)
Body fat (%)[e]				
Mean (SD)	37.1 (6.6)	35.2 (6.5)	34.4 (6.6)	35.5 (6.7)
< 25.00	1,197 (3.8)	4,842 (6.3)	2,524 (8.4)	8,563 (6.2)
25.00-29.99	3,256 (10.3)	11,220 (14.5)	4,920 (16.3)	19,396 (14.0)
30.00-34.99	7,011 (22.2)	20,467 (26.5)	8,224 (27.3)	35.702 (25.7)
35.00-39.99	9,129 (29.0)	22,181 (28.7)	8,347 (27.7)	39,657 (28.6)
≥ 40.00	10,940 (34.7)	18,506 (24.0)	6,110 (20.3)	35,556 (25.6)
Height (m)[f]				
< 1.55	2,758 (8.7)	6,315 (8.1)	2,810 (9.2)	11,883 (8.5)
1.55 - 1.59	6,268 (19.7)	15,551 (19.9)	6,504 (21.4)	28,323 (20.2)
1.60 - 1.64	10,067 (31.6)	24,437 (31.3)	9,631 (31.7)	44,135 (31.5)
1.65 - 1.69	7,993 (25.1)	20,091 (25.8)	7,530 (24.8)	35,614 (25.4)
≥ 1.70	4,779 (15.0)	11,621 (14.9)	3,952 (13.0)	20,352 (14.5)
Mean (SD) excess MET-hours per week[g]	5.3 (2.8)	25.5 (10.9)	83.0 (33.3)	33.4 (32.5)

Standing or walking job[h]	3,901 (17.4)	12,349 (25.7)	9,593 (56.3)	25,843 (29.53)
Manual job[i]	521 (2.3)	2,576 (5.4)	3,883 (22.8)	6,980 (8.0)
Smoking status[j]				
Never	19,513 (61.1)	47,974 (61.4)	18,370 (60.3)	85,857 (61.1)
Previous	9,468 (29.7)	24,366 (31.2)	9,635 (31.6)	43,469 (30.9)
Current	2,883 (9.0)	5,661 (7.2)	2,417 (7.9)	10,961 (7.8)
Alcohol consumption[k]				
Three or more times a week	12,670 (39.7)	33,747 (43.2)	12,137 (39.8)	58,554 (41.7)
Fruit and vegetable consumption[l]				
< 3.00 servings per day	6,601 (20.7)	9,849 (12.6)	3,070 (10.1)	19,520 (13.9)
3.00-3.99 servings per day	6,507 (20.4)	13,485 (17.3)	4,232 (13.9)	24,224 (17.2)
4.00-4.99 servings per day	6,672 (20.9)	16,489 (21.1)	5,701 (18.7)	28,862 (20.5)
5.00-5.99 servings per day	5,092 (16.0)	14,460 (18.5)	5,573 (18.3)	25,125 (17.9)
≥ 6.00 servings per day	6,874 (21.5)	23,557 (30.1)	11,740 (38.5)	42,171 (30.0)
Total red and processed meat consumption[m]				
< 2.00 times per week	5,462 (17.1)	15,254 (19.5)	6,729 (22.1)	27,445 (19.5)
2.00-2.99 times a week	10,903 (34.2)	27,329 (35.0)	10,190 (33.4)	48,422 (34.4)

3.00-3.99 times a week	5,395 (16.9)	12,642 (16.2)	4,823 (15.8)	22,860 (16.3)
4.00-4.99 times a week	4,058 (12.7)	9,143 (11.7)	3,423 (11.2)	16,624 (11.8)
≥ 5.00 times a week	5,973 (18.7)	13,456 (17.2)	5,144 (16.9)	24,573 (17.5)

Values are number (%) unless otherwise stated

Number of participants with missing data (the total number participants who have missing data, or who reported 'do not know' or 'prefer not to answer') for each characteristic is as follows: 0 for age, 263 for ethnicity, 150 for socioeconomic status, 756 for qualifications, 338 for BMI, 1,704 for body fat %, 271 for height, 0 for excess MET-hours/wk, 64 for standing or walking job, 52 for manual job, 291 for smoking status, 44 for alcohol consumption, 676 for fruit and vegetable consumption, 655 for total red and processed meat consumption

[a]Participants who reported their ethnicity as 'White', 'British', 'Irish', or 'Any other white background'

[b]We generated quintiles of socioeconmic status based on the Townsend deprivation index for the whole cohort (UK Biobank variable n_189_0_0)

[c]Vocational qualifications defined as other professional qualification (eg: nursing or teaching)/ National Vocational Qualification or Higher National Diploma or Higher National Certificate) (touchscreen question number D12, UK Biobank variable n_6138_0_0)

[d]We preferentially used BMI derived from height and weight measured during the impedance measurement (UK Biobank variable n_23104_0_0_), but if missing used the body size measures (UK Biobank variable n_21001_0_0); both of these are direct measures of height and weight made on the same day at the assessment centre.

[e]Body fat % (UK Biobank variable n_23099_0_0)

[f]Standing height (UK Biobank variable n_50_0_0)

[g]Excess MET-hours/wk estimated from the combination of reported walking, moderate and vigorous physical activity (for details see methods text)

[h]Participants who reported their work 'usually' or 'always' involved walking or standing for most of the time (touchscreen question number D9B, UK Biobank variable n_806_0_0)

[i]Participants who reported their work 'usually' or 'always' involved heavy manual or physical work for most of the time (touchscreen question number D9C, UK Biobank variable n_816_0_0)

[j]Smoking status (UK Biobank variable n_20116_0_0)

[k]Participants who reported consuming alcohol three to four times per week or daily or almost daily (touchscreen question number A1, UK Biobank variable n_1558_0_0)

[l]Total fruit and vegetable consumption is the sum of fresh fruit intake (touchscreen question number DT3, UK Biobank variable n_1309_0_0), cooked vegetable intake (touchscreen question numbers DT1, UK Biobank variable n_1289_0_0) and raw vegetable intake (touchscreen question number DT1, and UK Biobank variable n_1299_0_0). To sum the frequencies, 'Less than one' was coded as 0.5, and we coded 1 piece of fresh fruit as a serving and 2 tablespoons of vegetables as a serving.

[m]Total red and processed meat consumption is the sum of processed meat (touchscreen question number DT8 and UK Biobank variable n_1349_0_0), beef (touchscreen question number DT7 and UK Biobank variable n_1369_0_0), lamb/mutton (touchscreen question number DT7A and UK Biobank variable n_1379_0_0) , and pork (touchscreen question number DT7B and UK Biobank variable n_1389) intake. To sum the frequencies, we used the following coding: 'Never' = 0, 'Less than once a week' = 0.5, 'Once a week' = 1, '2-4 times a week' = 3, '5-6 times a week' = 5.5, 'Once or more daily' = 7.

Figure legends

Figure 1 UK Biobank participant flow diagram

MPA: moderate physical activity; VPA: vigorous physical activity

Figure 2 Body fat percentage by BMI in UK Biobank

Values are mean body fat % by single-unit BMI categories

Adjusted for age (5 year categories)

Error bars represent 1 SD either side of the mean

Estimates shown for cells with 200 or more participants

Figure 3 Mean BMI and body fat percentage by physical activity in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat % by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Adjusted for age (5 year categories)

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

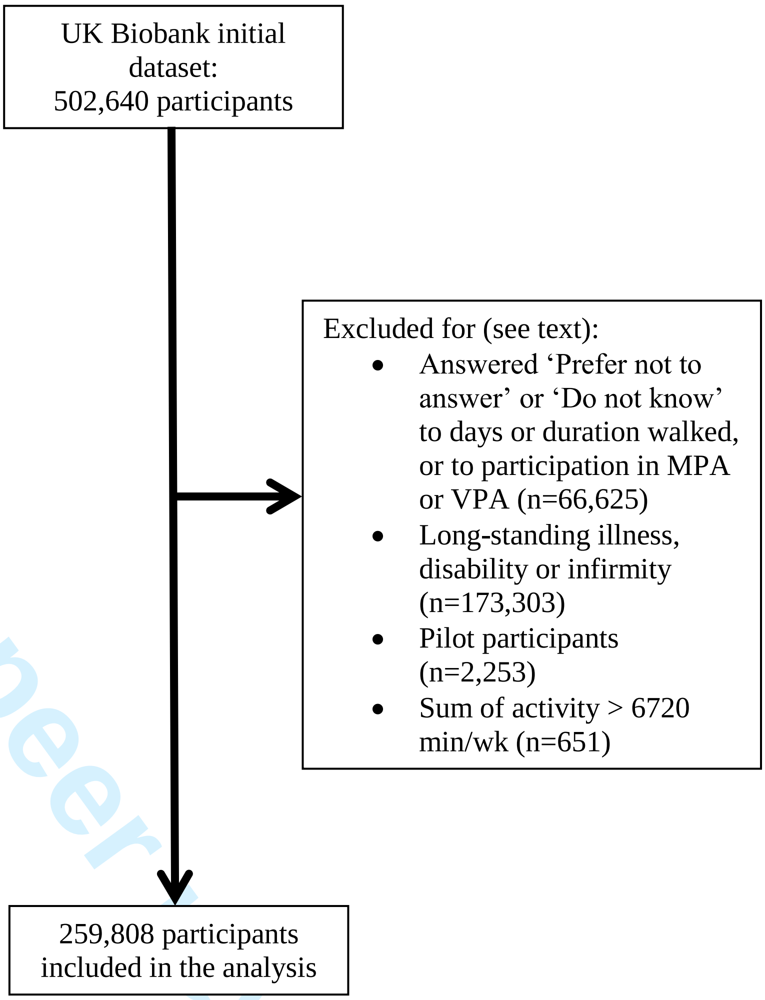
Figure 4 Mean body fat percentage by physical activity, stratified by BMI category in UK Biobank

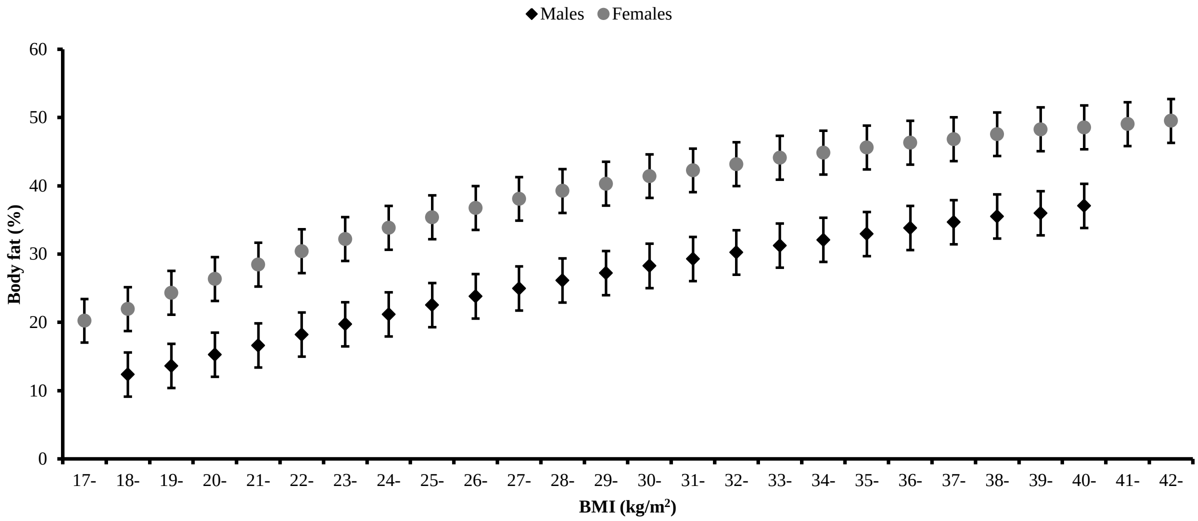
Panel A: men; Panel B: women

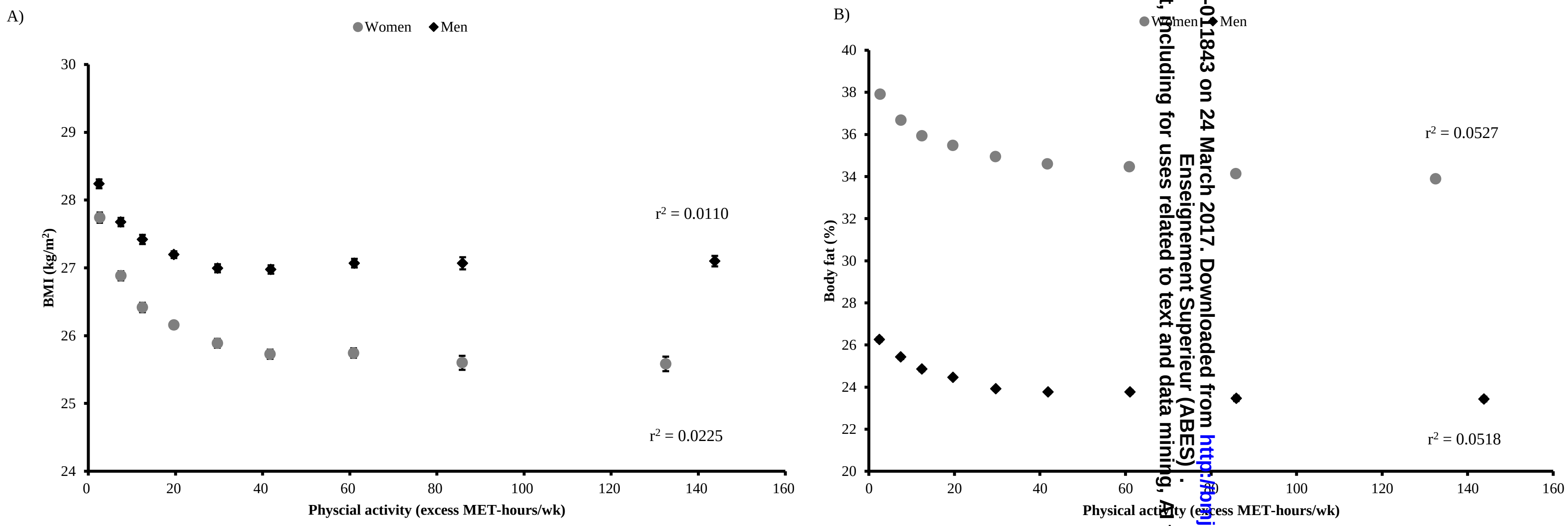
Values are mean body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Estimates shown for cells with 200 or more participants

Adjusted for age (5 year categories)


UK Biobank initial dataset:
502,640 participants
Excluded for (see text):
• Answered ‘Prefer not to answer’ or ‘Do not know’ to days or duration walked, or to participation in MPA or VPA (n=66,625)
• Long-standing illness, disability or infirmity (n=173,303)
• Pilot participants (n=2,253)
• Sum of activity > 6720 min/wk (n=651)
259,808 participants included in the analysis


Males
Females
Body fat (%)
60
50
40
30
20
10
0
17- 18- 19- 20- 21- 22- 23- 24- 25- 26- 27- 28- 29- 30- 31- 32- 33- 34- 35- 36- 37- 38- 39- 40- 41- 42-
BMI (kg/m2)


A)
Women
Men
BMI (kg/m²)
30
29
28
27
26
25
24
r² = 0.0110
r² = 0.0225
0
20
40
60
80
100
120
140
160
Physcial activity (excess MET-hours/wk)
B)
Women
Men
Body fat (%)
40
38
36
34
32
30
28
26
24
22
20
r² = 0.0527
r² = 0.0518
Physical activity (excess MET-hours/wk)

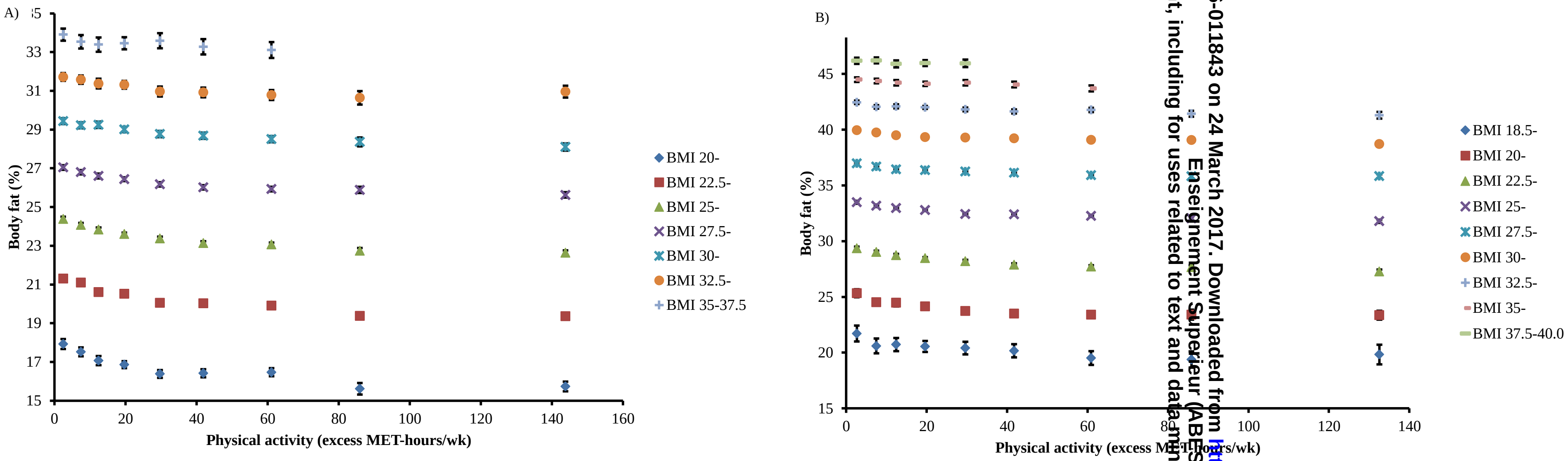

A)
Body fat (%)
Physical activity (excess MET-hours/wk)
BMI 20-
BMI 22.5-
BMI 25-
BMI 27.5-
BMI 30-
BMI 32.5-
BMI 35-37.5
B)
Body fat (%)
Physical activity (excess MET-hours/wk)
BMI 18.5-
BMI 20-
BMI 22.5-
BMI 25-
BMI 27.5-
BMI 30-
BMI 32.5-
BMI 35-
BMI 37.5-40.0

Table S1 Repeated measures of physical activity in men who completed the repeat assessment visit in UK Biobank 5 years after recruitment

	Physical activity (excess MET-hours per week)[a]								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
	All men (n = 119,230)								
Number of men	*12,613*	*13,792*	*12,381*	*20,983*	*15,023*	*14,635*	*13,415*	*7,043*	*9,345*
Baseline[b]	2.5	7.5	12.4	19.7	29.7	41.9	61.1	85.9	143.8
	Men who completed the repeat assessment visit (n = 5,158)								
Number of men	*602*	*614*	*534*	*943*	*691*	*631*	*541*	*279*	*323*
Baseline[b]	2.6	7.6	12.4	19.7	29.8	42.1	60.5	85.6	133.3
Repeat[b]	12.2	16.3	20.8	26.1	32.2	40.3	47.9	60.5	82.8

[a]Categories are defined from baseline data

[b]Values are mean excess MET-hours per week

Table S2 Repeated measures of physical activity in women who completed the repeat assessment visit in UK Biobank 5 years after recruitment

	Physical activity (excess MET-hours per week)[a]								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
	All women (n = 140,578)								
Number of women	*14,299*	*17,632*	*15,970*	*26,156*	*18,555*	*17,490*	*16,231*	*7,407*	6,838
Baseline[b]	2.6	7.5	12.4	19.6	29.6	41.7	60.9	85.8	132.5
	Women who completed the repeat assessment visit (n = 5,067)								
Number of women	*515*	*659*	*606*	*1,004*	*681*	*640*	*555*	*229*	*178*
Baseline[b]	2.6	7.6	12.3	19.6	29.7	41.7	61.0	85.0	133.0
Repeat[b]	11.9	18.5	21.3	26.1	33.2	40.6	52.8	59.2	80.7

[a]Categories are defined from baseline data

[b]Values are mean excess MET-hours per week

Table S3 Mean (95% CI) body fat percentage by categories of BMI and physical activity in men in UK Biobank.

Categories of BMI	Categories of physical activity (MET-hours/wk)								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
20-	16.6 (16.3-16.8) *n = 649*	16.1 (15.9-16.4) *n = 780*	15.7 (15.4-15.9) *n = 743*	15.4 (15.3-15.6) *n = 1356*	14.9 (14.7-15.1) *n = 1014*	15.0 (14.7-15.2) *n = 986*	15.0 (14.8-15.2) *n = 940*	14.1 (13.8-14.4) *n = 478*	14.3 (14.0-14.6) *n = 658*
Mean BMI	*21.6*	*21.5*	*21.5*	*21.5*	*21.5*	*21.5*	*21.6*	*21.5*	*21.5*
22.5-	19.9 (19.8-20.1) *n = 1943*	19.7 (19.6-19.8) *n = 2477*	19.2 (19.0-19.3) *n = 2411*	19.1 (19.0-19.2) *n = 4289*	18.6 (18.5-18.7) *n = 3379*	18.6 (18.4-18.7) *n = 3247*	18.4 (18.3-18.6) *n = 2851*	17.9 (17.7-18.1) *n = 1490*	17.9 (17.8-18.1) *n = 1909*
Mean BMI	*23.9*	*23.9*	*23.9*	*23.9*	*23.9*	*23.9*	*23.8*	*23.9*	*23.8*
25-	23.0 (22.9-23.1) *n = 3217*	22.7 (22.6-22.8) *n = 3861*	22.4 (22.3-22.5) *n = 3606*	22.2 (22.1-22.3) *n = 6180*	21.9 (21.8-22.0) *n = 4428*	21.7 (21.6-21.8) *n = 4419*	21.6 (21.5-21.7) *n = 3960*	21.3 (21.1-21.4) *n = 2095*	21.2 (21.1-21.3) *n = 2694*
Mean BMI	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*
27.5-	25.7 (25.6-25.8) *n = 2950*	25.4 (25.3-25.5) *n = 3192*	25.2 (25.1-25.3) *n = 2793*	25.0 (24.9-25.1) *n = 4818*	24.7 (24.6-24.9) *n = 3302*	24.6 (24.4-24.7) *n = 3199*	24.5 (24.3-24.6) *n = 2948*	24.4 (24.2-24.6) *n = 1561*	24.2 (24.0-24.3) *n = 2145*
Mean BMI	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*
30-	28.1 (27.9-28.2) *n = 1867*	27.8 (27.7-28.0) *n = 1780*	27.8 (27.7-28.0) *n = 1498*	27.6 (27.4-27.7) *n = 2409*	27.3 (27.2-27.5) *n = 1644*	27.2 (27.1-27.4) *n = 1585*	27.1 (26.9-27.2) *n = 1560*	26.9 (26.7-27.1) *n = 809*	26.7 (26.5-26.9) *n = 1107*
Mean BMI	*31.1*	*31.1*	*31.1*	*31.0*	*31.0*	*31.0*	*31.0*	*31.0*	*31.0*
32.5-	30.4 (30.2-30.6) *n = 984*	30.2 (30.0-30.4) *n = 873*	30.0 (29.7-30.2) *n = 663*	29.9 (29.7-30.1) *n = 1009*	29.5 (29.3-29.8) *n = 654*	29.5 (29.2-29.7) *n = 634*	29.3 (29.1-29.6) *n = 614*	29.2 (28.8-29.6) *n = 335*	29.5 (29.2-29.8) *n = 440*
Mean BMI	*33.6*	*33.6*	*33.5*	*33.5*	*33.4*	*33.5*	*33.5*	*33.5*	*33.5*

35-	32.5 (32.2-32.9) *n = 428*	32.1 (31.8-32.5) *n = 358*	32.0 (31.6-32.4) *n = 302*	32.0 (31.7-32.3) *n = 416*	32.2 (31.8-32.5) *n = 280*	31.8 (31.4-32.2) *n = 261*	31.7 (31.3-32.1) *n = 247*	-	-
Mean BMI	*36.1*	*36.0*	*36.0*	*36.0*	*36.0*	*36.0*	*36.0*		
37.5-	34.3 (33.9-34.8) *n = 217*	-	-	-	-	-	-	-	-
Mean BMI	*38.5*								

Adjusted for age (5 year categories)
Values not shown for cells with less than 200 participants

Table S4 Mean (95% CI) body fat percentage by categories of BMI and physical activity in women in UK Biobank

Categories of BMI	Categories of physical activity (MET-hours/wk) <5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
18.5-	24.4 (24.0-24.8) *n = 313*	23.5 (23.2-23.9) *n = 460*	23.5 (23.2-23.8) *n = 405*	23.1 (22.9-23.4) *n = 749*	22.7 (22.4-23.0) *n = 569*	22.5 (22.2-22.7) *n = 556*	22.3 (22.0-22.6) *n = 526*	22.3 (21.9-22.8) *n = 219*	22.3 (21.9-22.7) *n = 267*
Mean BMI	*19.4*	*19.3*	*19.4*	*19.4*	*19.4*	*19.4*	*19.4*	*19.3*	*19.4*
20-	28.4 (28.2-28.6) *n = 1657*	28.0 (27.9-28.2) *n = 2333*	27.8 (27.6-27.9) *n = 2378*	27.5 (27.4-27.6) *n = 4095*	27.2 (27.1-27.3) *n = 3115*	26.8 (26.7-27.0) *n = 3034*	26.7 (26.5-26.8) *n = 2746*	26.6 (26.4-26.8) *n = 1327*	26.2 (26.0-26.4) *n = 1156*
Mean BMI	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*
22.5-	32.6 (32.4-32.7) *n = 2872*	32.2 (32.1-32.3) *n = 4068*	32.0 (31.9-32.1) *n = 4014*	31.8 (31.7-31.9) *n = 6819*	31.4 (31.3-31.5) *n = 4981*	31.4 (31.3-31.5) *n = 4820*	31.2 (31.1-31.3) *n = 4496*	31.0 (30.8-31.2) *n = 2026*	30.7 (30.6-30.9) *n = 1998*
Mean BMI	*23.8*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*
25-	36.0 (35.9-36.2) *n = 2953*	35.7 (35.6-35.8) *n = 4016*	35.4 (35.3-35.6) *n = 3594*	35.4 (35.3-35.5) *n = 6034*	35.2 (35.1-35.3) *n = 4288*	35.1 (35.0-35.2) *n = 4069*	34.9 (34.8-35.0) *n = 3705*	34.8 (34.6-35.0) *n = 1692*	34.8 (34.6-35.0) *n = 1516*
Mean BMI	*26.2*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*
27.5-	39.0 (38.9-39.2) *n = 2353*	38.8 (38.6-38.9) *n = 2715*	38.5 (38.4-38.7) *n = 2370*	38.3 (38.2-38.5) *n = 3704*	38.3 (38.2-38.4) *n = 2616*	38.2 (38.1-38.4) *n = 2366*	38.1 (37.9-38.2) *n = 2262*	38.0 (37.8-38.2) *n = 1008*	37.7 (37.5-37.9) *n = 879*
Mean BMI	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*
30-	41.5 (41.3-41.7) *n = 1625*	41.1 (40.9-41.3) *n = 1716*	41.1 (40.9-41.3) *n = 1424*	41.0 (40.9-41.2) *n = 2185*	40.8 (40.6-41.0) *n = 1366*	40.6 (40.4-40.8) *n = 1237*	40.8 (40.6-41.0) *n = 1181*	40.4 (40.1-40.7) *n = 564*	40.3 (40.0-40.6) *n = 468*
Mean BMI	*31.1*	*31.1*	*31.1*	*31.1*	*31.1*	*31.0*	*31.1*	*31.0*	*31.1*
32.5-	43.6	43.4	43.2	43.1	43.2	43.0	42.7	42.7	42.5

	(43.4-43.8)	(43.2-43.6)	(43.0-43.5)	(42.9-43.3)	(43.0-43.5)	(42.8-43.3)	(42.4-43.0)	(42.3-43.1)	(42.0-42.9)
	n = 1008	*n = 989*	*n = 774*	*n = 1149*	*n = 699*	*n = 651*	*n = 611*	*n = 260*	*n = 233*
Mean BMI	*33.6*	*33.6*	*33.6*	*33.6*	*33.6*	*33.5*	*33.5*	*33.5*	*33.5*
35-	45.3 (45.0-45.5) *n = 577*	45.2 (45.0-45.5) *n = 577*	44.9 (44.6-45.3) *n = 444*	45.0 (44.7-45.3) *n = 584*	44.9 (44.6-45.3) *n = 359*	44.9 (44.5-45.3) *n = 313*	44.8 (44.4-45.2) *n = 282*	-	-
Mean BMI	*36.1*	*36.1*	*36.0*	*36.1*	*36.1*	*36.1*	*36.0*		
37.5-	47.0 (46.6-47.3) *n = 368*	46.6 (46.2-47.0) *n = 303*	46.8 (46.3-47.2) *n = 207*	46.7 (46.3-47.1) *n = 316*	46.6 (46.1-47.0) *n = 205*	-	-	-	-
Mean BMI	*38.6*	*38.5*	*38.6*	*38.5*	*38.5*				
40-	48.3 (47.8-48.7) *n = 220*	-	-	-	-	-	-	-	-
Mean BMI	*41.1*								

Adjusted for age (5 year categories)

Values not shown for cells with less than 200 participants

Table S5 BMI and body fat percentage by sex and 5-year age category in UK Biobank

	n	BMI	Body fat percentage
Men			
< 45 years	15176	27.2 (4.0)	22.8 (5.5)
45-49 years	17569	27.4 (3.9)	23.5 (5.5)
50-54 years	18375	27.5 (3.9)	24.1 (5.5)
55-59 years	20580	27.3 (3.8)	24.6 (5.5)
60-64 years	26532	27.3 (3.7)	25.1 (5.4)
≥ 65 years	20671	27.1 (3.6)	25.6 (5.3)
Women			
< 45 years	17392	25.7 (4.8)	33.7 (7.0)
45-49 years	21848	26.0 (4.8)	34.3 (7.0)
50-54 years	23728	26.3 (4.7)	35.3 (6.7)
55-59 years	25329	26.3 (4.6)	35.9 (6.5)
60-64 years	31600	26.5 (4.4)	36.4 (6.3)
≥ 65 years	20343	26.5 (4.2)	36.7 (6.0)

Values are mean (SD)

Numbers of participants shown are for BMI within each age category, slightly fewer participants have information on body fat percentage

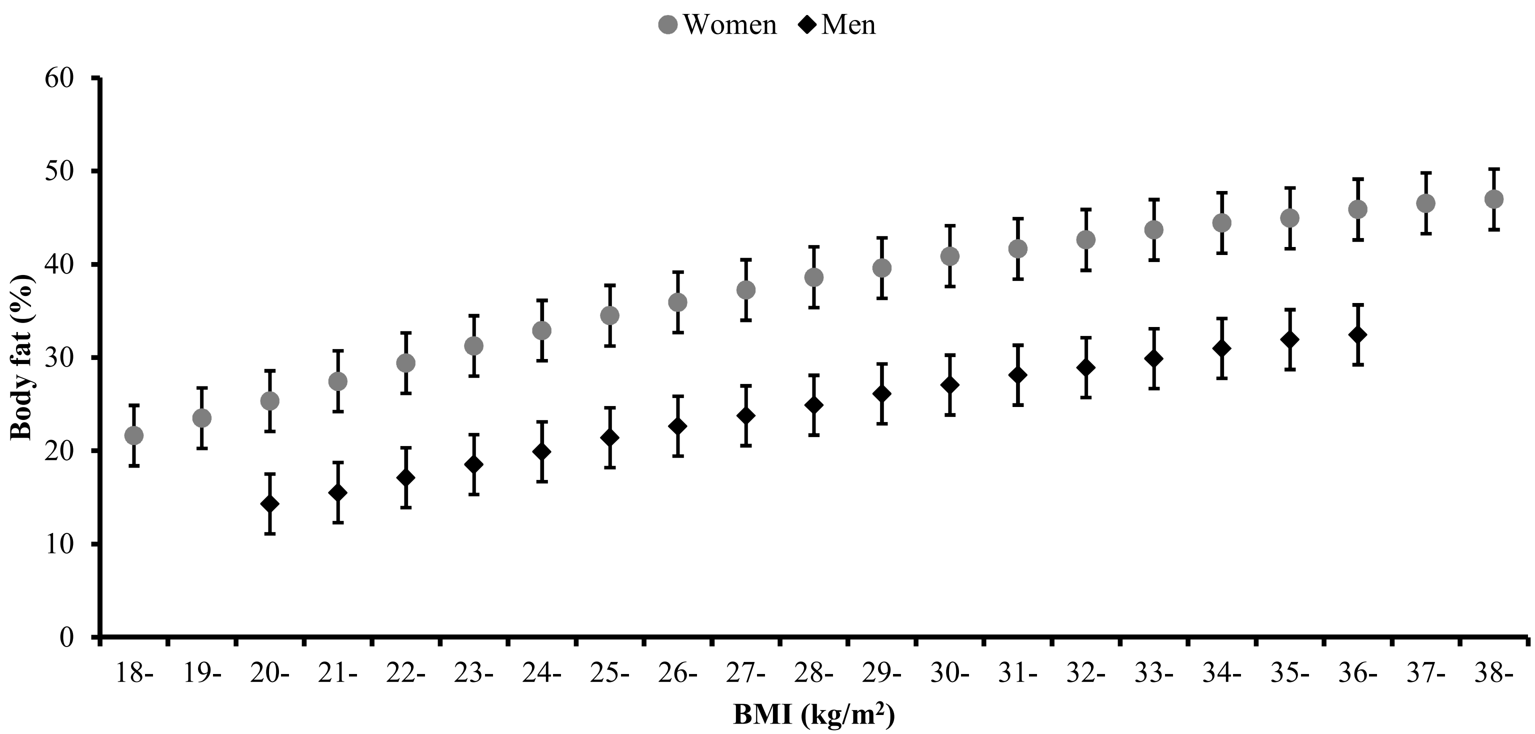


Figure S1 Body fat percentage by BMI for participants aged younger than 50 years in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

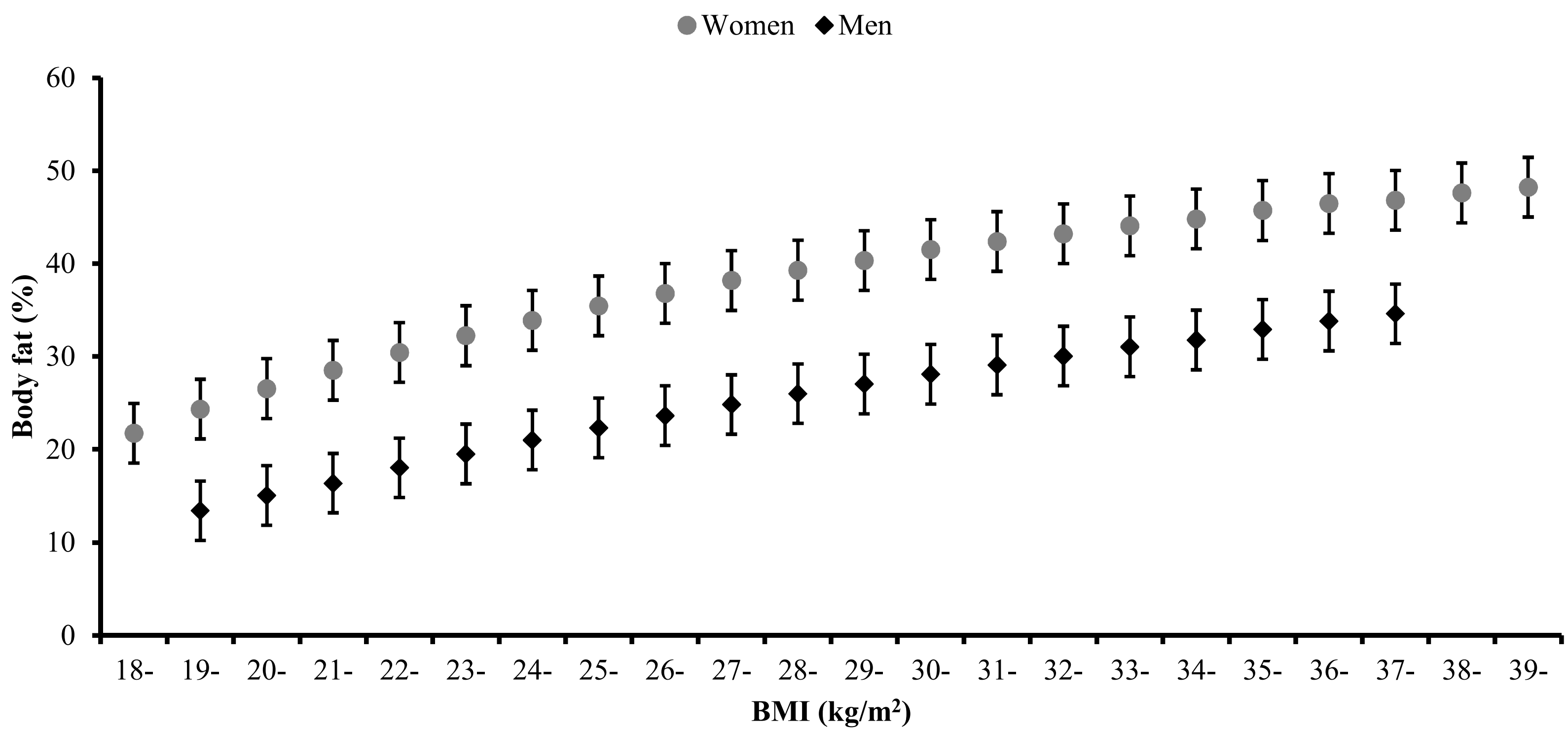


Figure S2 Body fat percentage by BMI for participants aged 50-59 years in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

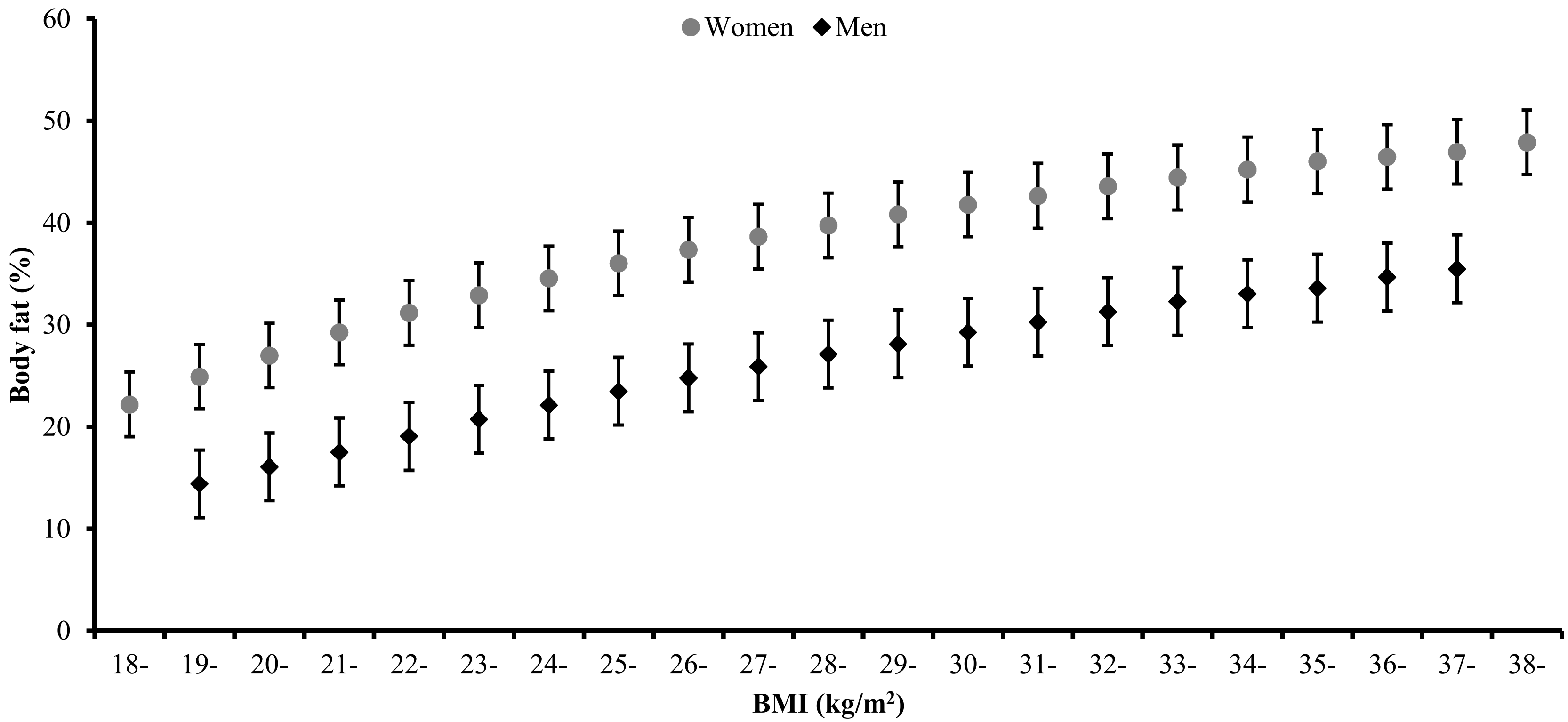


Figure S3 Body fat percentage by BMI for participants aged 60 years or older in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

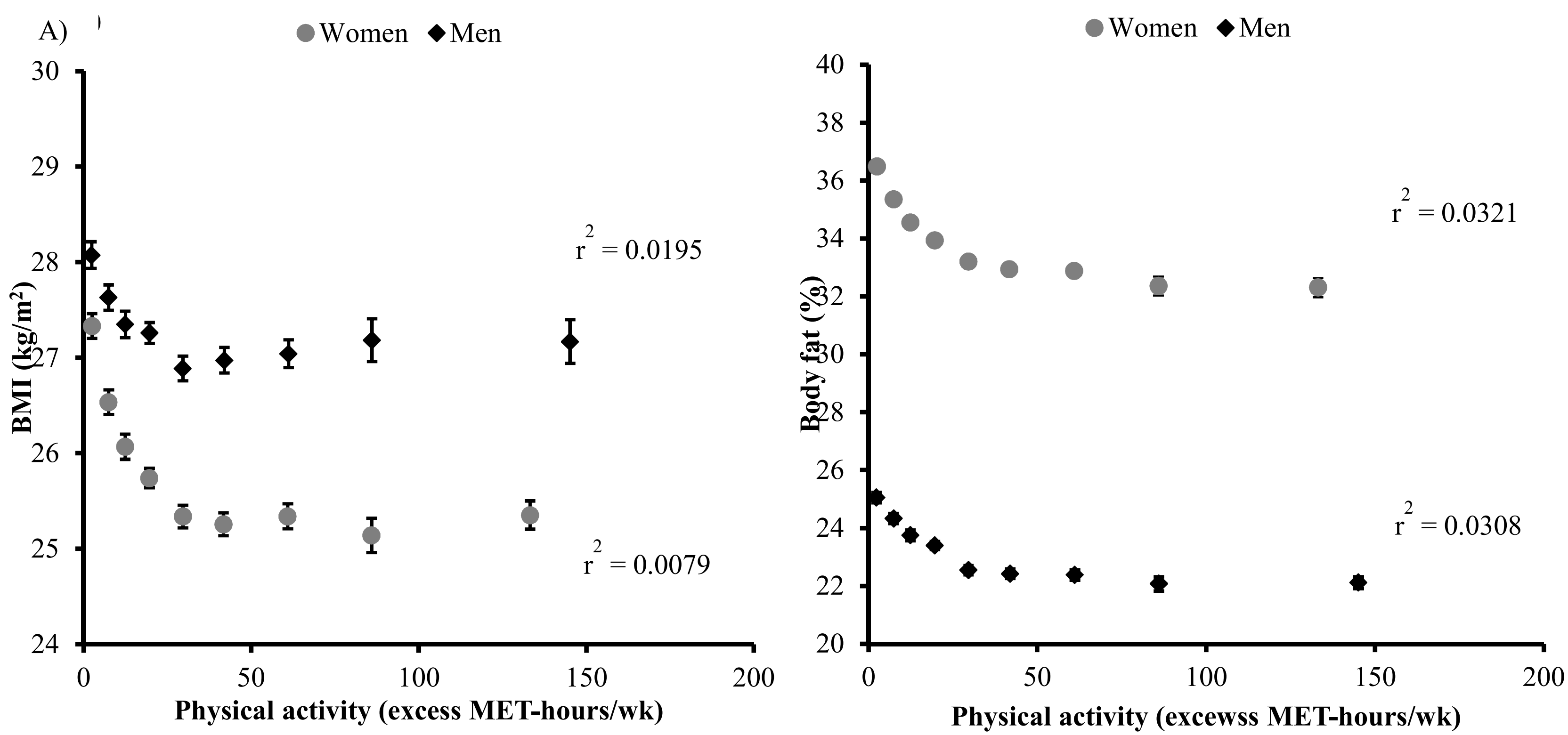


Figure S4 Mean BMI and body fat percentage by physical activity for participants aged younger than 50 years in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

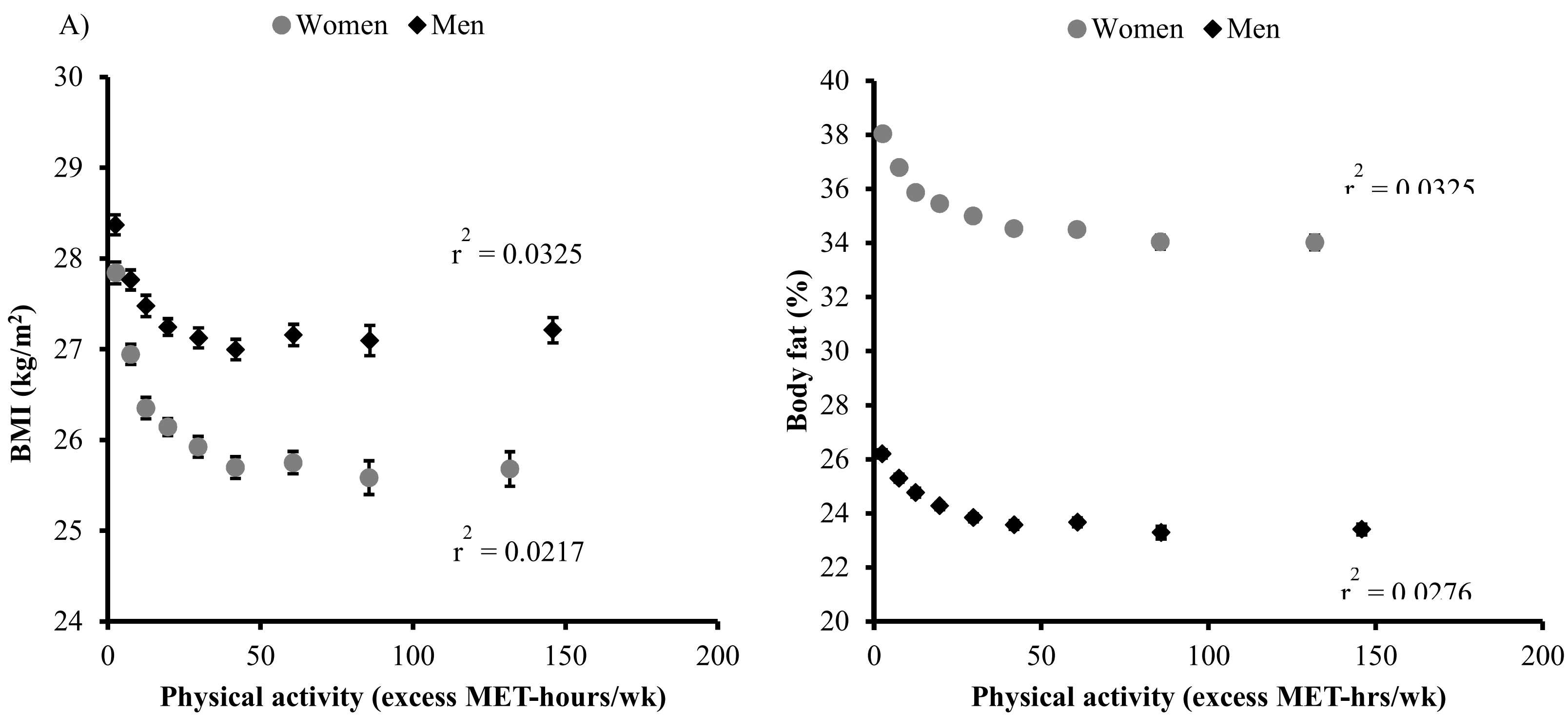


Figure S5 Mean BMI and body fat percentage by physical activity in participants aged 50-59 years in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

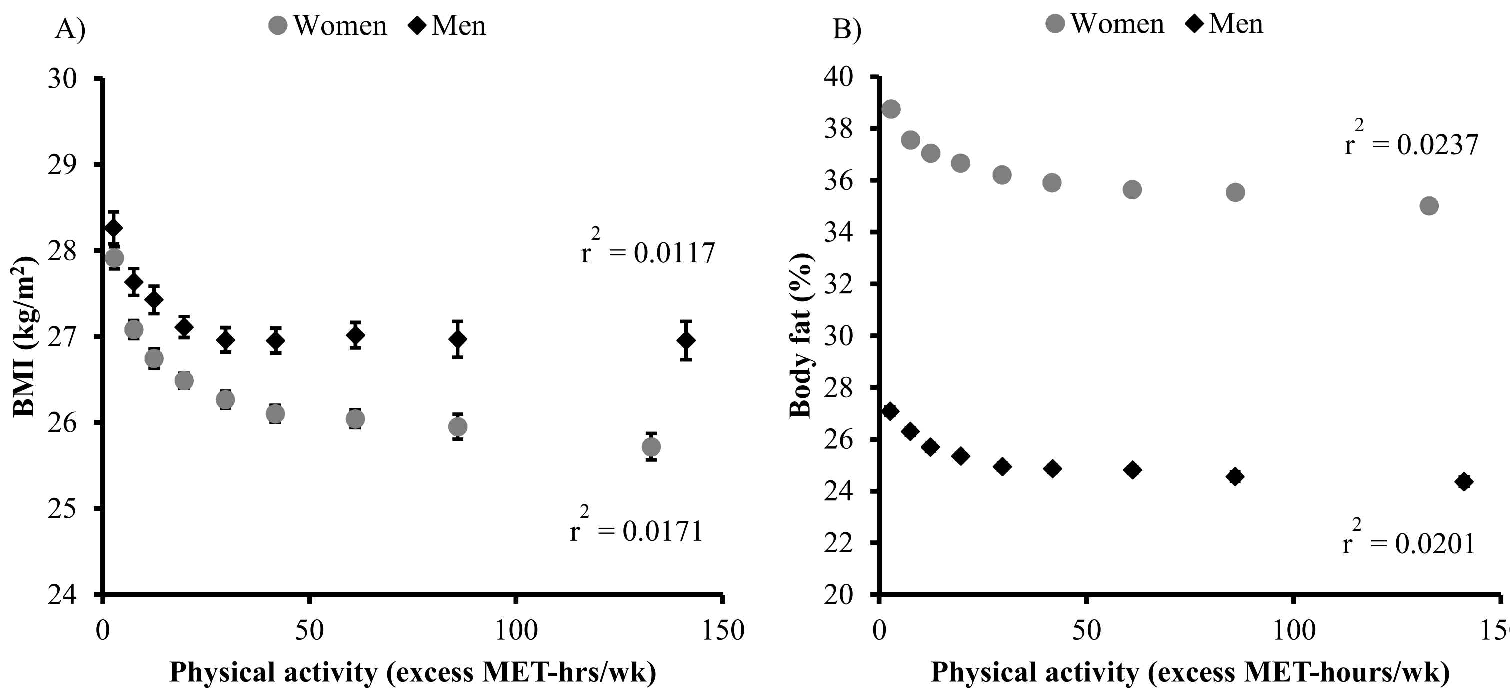


Figure S6 Mean BMI and body fat percentage by physical activity in participants aged 60 years or older in UK Biobank
Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)
Values are mean BMI and body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Errors bars are 95% CI
Estimates shown for cells with 200 or more participants

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract Title, and Pg 3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found Pg 3
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Pg 5
Objectives	3	State specific objectives, including any prespecified hypotheses Pg 5
Methods		
Study design	4	Present key elements of study design early in the paper Pg 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Pg 6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants Pg 8
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Pg 9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Pgs 6-8, and Footnotes for Table 1 and Table 2
Bias	9	Describe any efforts to address potential sources of bias Pg 10
Study size	10	Explain how the study size was arrived at Pg 8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Pg 9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding Pgs 9-10
		(*b*) Describe any methods used to examine subgroups and interactions Pgs 9-10
		(*c*) Explain how missing data were addressed Pg 8
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(*e*) Describe any sensitivity analyses Pg 9

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Pg 12, and Figure 1
		(b) Give reasons for non-participation at each stage Figure 1
		(c) Consider use of a flow diagram Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Pg 12, and Tables 1 and 2
		(b) Indicate number of participants with missing data for each variable of interest Footnotes for Tables 1 and 2
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures Tables 1 and 2.
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included Pgs 12-13
		(*b*) Report category boundaries when continuous variables were categorized Pgs 9-10
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Pgs 13-14
Discussion		
Key results	18	Summarise key results with reference to study objectives Pg 15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Pgs 15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence Pg 17
Generalisability	21	Discuss the generalisability (external validity) of the study results Pgs 16-17
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based Pg 18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Physically active adults have lower body fat percentage, after adjusting for BMI: a cross-sectional analysis of UK Biobank

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-011843.R1
Article Type:	Research
Date Submitted by the Author:	04-Aug-2016
Complete List of Authors:	Bradbury, Kathryn; University of Oxford, Cancer Epidemiology Unit, Nuffield Department of Population Health Guo, Wenji; University of Oxford, Cancer Epidemiology Unit, Nuffield Department of Population Health Cairns, Benjamin; University of Oxford, Cancer Epidemiology Unit Armstrong, Miranda; University of Oxford, Cancer Epidemiology Unit, Nuffield Department of Population Health Key, Timothy; Oxford University, Cancer Research U.K. Epidemiology Unit, Unive
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Sports and exercise medicine, Research methods, Public health
Keywords:	Physical activity, UK Biobank, BMI, Body fat percentage

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Physically active adults have lower body fat percentage, after adjusting for BMI: a cross-sectional analysis of UK Biobank

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Abstract

Objectives: The objective of this study was to examine if physically active adults have less body fat after taking BMI into account.

Design: A cross-sectional analysis of participants recruited into UK Biobank in 2006-2010.

Setting: UK Biobank assessment centres throughout the UK.

Participants: 119,230 men and 140,578 women aged 40-69 years, with complete physical activity information, and without a self-reported long-term illness, disability or infirmity.

Exposures: Physical activity measured as excess MET-hours per week, estimated from a combination of walking, and moderate and vigorous physical activity. BMI from measured height and weight.

Main outcome measure: Body fat percentage estimated from bio-impedance.

Results: BMI and body fat percentage were highly correlated (r=0.85 in women; r=0.79 in men), and both were inversely associated with physical activity. Compared to <5 excess metabolic equivalent (MET)-hours per week at baseline, ≥100 excess MET-hours per week was associated with a 1.1 kg/m^2 lower BMI (27.1 versus 28.2 kg/m^2) and 2.8 percentage points lower body fat (23.4% versus 26.3%) in men, and 2.2 kg/m^2 lower BMI (25.6 versus 27.7 kg/m^2) and 4.0 percentage points lower body fat (33.9% versus 37.9%) in women. For a given BMI, greater physical activity was associated with lower average body fat percentage (for a BMI of 22.5-24.99 kg/m^2: 2.0 (95% CI: 1.8 to 2.2) percentage points lower body fat in men, and 1.8 (95% CI: 1.6 to 2.0) percentage points lower body fat in women, comparing ≥100 excess MET-hours per week to <5 excess MET-hours per week).

Conclusions: Physical activity was inversely associated with BMI and body fat percentage. For people with the same BMI, those who were more active had a lower body fat percentage.

Strengths and limitations of this study

- This study of older adults, drawn from the general population, is very large (n = 259,808) and height and weight (for the calculation of BMI) were measured by trained staff using standardised techniques.
- Body fat percentage (estimated via bio-impedance) was available for virtually all participants.
- Physical activity was self-reported and therefore there will be some measurement error associated with this variable.
- The study is cross-sectional and therefore we cannot infer cause and effect.

Introduction

Body mass index (BMI) is a simple index calculated from height and weight, and is usually used as a proxy for body fatness in large epidemiological studies. Correlations between BMI and more direct measures of body fatness are generally strong (r > 0.70) (1-3).

Observational studies have shown that people who do comparatively more physical activity have a lower BMI than less active people (4, 5). Few large epidemiological studies have directly estimated body fatness, and it is of interest to examine whether more comprehensive measures of body fatness provide additional information above and beyond that which is captured by BMI. Previous studies each of approximately 500 young adults have found that, for a given BMI, athletes have a lower body fat percentage than non-athletes (6, 7); however it is unclear whether in the general population, including older adults, those who do more physical activity have a lower body fat percentage than those who do minimal physical activity, after taking into account BMI.

UK Biobank is a population-based cohort of 500,000 UK men and women, aged 40-69 years at recruitment. Body mass index and body fat percentage were measured at recruitment for virtually all participants. For this analysis of data from UK Biobank we aimed firstly to describe the associations of physical activity with BMI and body fat percentage, and secondly to determine whether physical activity is associated with body fat percentage, independently of BMI.

METHODS

Subjects

UK Biobank is a prospective cohort of approximately 500,000 people aged 40-69 years, recruited in 2006-2010 in the UK (8). People aged 40-69 years who lived within reasonable travelling distance of 22 assessment centres were identified from National Health Service patient registers and invited to participate in UK Biobank by attending an assessment centre. Permission for access to patient records for recruitment was approved by the National Information Governance Board for Health and Social Care in England and Wales, and the Community Health Index Advisory Group in Scotland. A sub-sample of approximately 20,000 participants completed a full repeat of the assessment centre visit between August 2012 and June 2013, approximately 5 years after recruitment (9). UK Biobank has ethical approval from the North West Multi-centre Research Ethics Committee. The UK Biobank protocol is available online (http://www.ukbiobank.ac.uk/wp-content/uploads/2011/11/UK-Biobank-Protocol.pdf). The touchscreen questionnaire and other resources are also available on the UK Biobank website (http://www.ukbiobank.ac.uk/resources/).

Anthropometric measurements

At the UK Biobank assessment centres, a touchscreen questionnaire was used to collect information on socio-demographic characteristics and lifestyle exposures. Socks and shoes were removed and height was measured using the Seca 202 height measure (Seca, Hamburg, Germany). Weight and estimated percentage fat were measured with the Tanita BC418ma bio-impedance device (Tanita, Tokyo, Japan). Participants were not asked to fast, nor were they given any specific instructions pertaining to the bio-impedance measures prior to attending the assessment centre. Water was available at all times throughout the visit and visits occurred throughout the day (8am-8pm).

Physical activity assessment

Questions on the touchscreen about walking, moderate physical activity, and vigorous physical activity, which were similar to those used in the short form of the International Physical Activity Questionnaire (10), were used to estimate excess metabolic equivalents (MET)-hours per week of physical activity during work and leisure time. For each of the three activity categories (walking, moderate physical activity, and vigorous physical activity) participants were asked how many days in a typical week they did each of the activities for 10 minutes or more (for walking: touchscreen question number WP1, UK Biobank variable n_864_0_0; for moderate physical activity: touchscreen question number WP2, UK Biobank variable n_884_0_0; for vigorous physical activity: touchscreen question number WP3, UK Biobank variable n_904_0_0). For each category, participants who entered one or more days were then asked how many minutes they spent doing those activities on a typical day (for walking: WP1A, n_874_0_0; for moderate physical activity: WP2A, n_894_0_0; for vigorous physical activity: WP3A, n_914_0_0). For each activity category, the number of reported days was multiplied by the number of reported minutes on a typical day to generate duration of activity in minutes per week.

Activity on a typical day of less than 10 minutes was recoded to 0 for any of the three categories of activity. For each of the three categories of activity, values of more than 1260 minutes per week (equivalent to an average of 3 hours per day) were truncated at 1260 (10).

Total MET values for each category from the International Physical Activity Questionnaire short form were: 3.3 for walking, 4.0 for moderate physical activity, and 8.0 for vigorous physical activity (10). We report excess METs, which are calculated by subtracting 1 MET from the value for each activity, and represent the energy expenditure above that of an inactive person (11). Excess MET values were therefore 2.3 for walking, 3.0 for moderate physical activity, and 7.0 for vigorous physical activity. Excess MET-hours per week were calculated by multiplying the excess MET value for each activity by the duration of activity in hours per week (10).

Exclusions

The UK Biobank dataset used for this analysis included 502,640 participants. Participants were excluded from this analysis if they selected 'Prefer not to answer' or 'Do not know' to any of the possible six questions on physical activity (WP1, WP1A, WP2, WP2A, WP3, WP3A) (n = 66,625). Participants were also excluded from this analysis if they responded to the question: "Do you have a long-term illness, disability or infirmity?" with 'Yes' (n = 159,941), 'Prefer not to answer' (n = 1,052) or 'Do not know' (n = 11,391), or if they had a missing value for this variable (n = 919) (touchscreen question number H4, UK Biobank variable n_2188_0_0). In addition, the questions used in the pilot study on the duration of physical activity differed from those in the main study, and participants who answered the pilot version of these questions were excluded (n = 2,253). Based on the International Physical Activity Questionnaire recommendations for data cleaning and processing (10), participants were also excluded from the analysis if the sum of walking, moderate physical activity, and vigorous physical activity was greater than 112 hours per week (n = 651), leaving a total of 259,808 participants in the present study.

Statistics

STATA version 14.0 (Stata Corp LP, College Station, TX) was used for all statistical analyses. All analyses were done for men and women separately. Participant characteristics were described by level of physical activity (low, < 10.0; moderate, 10.0-49.9; high, ≥ 50 excess MET-hours per week). Pearson's correlation coefficients between BMI and body fat percentage were calculated; values of 0.80 or above are considered very strong, values between 0.60-0.79 strong, 0.40-0.59 moderate, 0.20-0.39 weak, and 0.00-0.19 very weak (12). Multiple linear regression was used to calculate the mean body fat percentage in single units of BMI (e.g. 17.00-17.99, 18.00-18.99, 19.00-19.99 kg/m^2, etc), adjusted for age (5 year categories: < 45 years, 45-49.99 years, 50-54.99 years, 55-59.99 years, 60-64.99 years, ≥ 65.00 years). Groups with 200 or more participants are shown in the Figure. Multiple linear regression was also used to calculate mean BMI and body fat percentage in categories of excess MET-hours per week (< 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hours per week), adjusted for age (5 year categories, as above). For the final analysis, we used multiple linear regression to examine the association between physical activity (in excess MET-hours per week: < 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100) and body fat percentage (continuous variable). Body mass index (in 2.5 unit categories, e.g. < 18.50, 18.50-19.99, 20.00-22.49, 22.50-24.99, 25.00-27.49…,42.50-44.99, ≥ 45.00 kg/m^2, etc) and age (5 year categories) were included as covariates. We included a product term of excess MET-hours per week (categories, as above) and BMI (in 2.5 unit categories as above) in the model to calculate mean body fat percentage in categories of physical activity within strata of BMI. In additional sensitivity analyses, we adjusted for reported intakes of fruit and vegetables (< 3.00 servings/week, 3.00-3.99, 4.00-4.99, 5.00-5.99, ≥ 6.00 servings/week, unknown), and red and processed meat (< 2.00 servings/week, 2.00-2.99, 3.00-3.99, 4.00-4.99, ≥ 5.00 servings/week, unknown). We also restricted the analysis to those with a university or college degree, and separately, to those that do not have a job that usually or always involves standing or walking or manual work.

We also examined mean BMI and body fat percentage in 5 year age categories. For each age decade separately (i.e. participants < 50 years, 50-59 years, and ≥ 60 years) linear regression was used to calculate mean body fat percentage in single units of BMI, and to calculate mean BMI and body fat percentage in each category of physical activity (< 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hours per week).

To explore the repeatability of self-reported physical activity, including effects of measurement error and possible changes in activity over time, we used a sub-sample of 10,225 UK Biobank participants who were eligible for the current study and who completed a repeat assessment visit approximately 5 years after recruitment (Supplementary Tables S1 and S2). For these participants, we calculated excess MET-hours per week from their answers to the touchscreen questionnaire completed at the repeat assessment centre visit, as described above. Then for each category of excess MET-hours per week defined at baseline, we calculated both the mean excess MET-hours per week at their baseline visit (to assess comparability of the sub-sample to the full cohort) and the mean excess MET-hours per week at the repeat visit (to assess measurement error in reporting physical activity and change over time). The sub-sample of participants who completed a repeat assessment centre visit approximately 5 years after recruitment was similar at baseline to the full cohort with regard to reported physical activity. However, at the repeat assessment, for participants in the highest category of physical activity defined at baseline (≥ 100 excess MET-hours per week), the mean excess MET-hours per week was much lower than at baseline (80 compared to 130 for both men and women). For the lowest category of physical activity defined at baseline, the mean excess MET-hours per week was somewhat higher at the repeat assessment than at baseline (12 compared to 2.6 for both men and women). Overall, this represents regression to the mean of almost 50% (calculated from the ratio of the range of mean values at the repeat assessment to the range of mean values at baseline). The Pearson's correlation coefficients between recruitment and repeat measurements of BMI and body fat percentage in the sub-sample of participants who completed a repeat assessment centre visit were 0.92 for both BMI and body fat percentage.

All p values were two-sided and $P < 0.05$ was considered statistically significant.

RESULTS

Participant flow is shown in Figure 1. Participants who had a high level of physical activity were older, had a lower BMI, a lower body fat percentage, and a higher intake of fruit and vegetables than participants with a low level of physical activity (Table 1 and Table 2). They were also less likely to have a college or university degree, and much more likely to have a standing or manual job than those with a moderate or low level of physical activity. Participants with a moderate activity level were the least likely to be current smokers.

Body fat percentage was positively related to BMI (Figure 2). The correlation between BMI and body fat percentage was very strong in women (r = 0.85), and strong in men (r = 0.79). At the same BMI, women had a much higher body fat percentage than men; for example, women with a BMI of 30.00-30.99 kg/m^2 had on average 41% body fat, whereas men with the same BMI had on average 28% body fat.

Body fat percentage and BMI were inversely related to physical activity (Figure 3). Men who did < 5 excess MET-hours of physical activity per week had, on average, a BMI of 28.2 kg/m^2 (95% Confidence Interval (CI): 28.2 to 28.3 kg/m^2) and 26.3% (95% CI: 26.2 to 26.4 kg/m^2) body fat. Men who did ≥100 excess MET-hours per week of physical activity per week had, on average, a BMI of 27.1 kg/m^2 (95% CI: 27.0 to 27.2 kg/m^2) and 23.4% (95% CI: 23.3 to 23.5%) body fat. Women who did < 5 excess MET-hours per week of physical activity per week had, on average, a BMI of 27.7 kg/m^2 (95% CI: 27.7 to 27.8 kg/m^2) and 37.9% (95% CI: 37.8 to 38.0%) body fat. Women who did ≥ 100 excess MET-hours per week of physical activity per week had, on average, a BMI of 25.6 kg/m^2 (95% CI: 25.5 to 25.7 kg/m^2) and a 33.9% (95% CI: 33.7 to 34.0%) body fat. For both men and women, as shown by the r^2 values, age and physical activity explained more of the variation in body fat

percentage than the variation in BMI in this study population; however, age and physical activity only explained a small proportion of the variation in both BMI and body fat percentage in this study population, with all r^2 values less than 0.06 (Figure 3).

Overall, in males, those doing ≥ 100 or more excess MET-hours per week compared with < 5 excess MET-hours per week had a 1.7 (95% CI: 1.6 to 1.7) percentage points lower body fat percentage, on average, after adjustment for BMI and age; in females it was on average 1.5 (95% CI: 1.4 to 1.6) percentage points lower. For both men and women, within each stratum of BMI, a higher physical activity level was associated with a lower body fat percentage, and the difference in body fat percentage between physical activity categories appeared to be slightly larger at lower BMIs (p for interaction using likelihood ratio test < 0.001, for both sexes) (Figure 4, Supplementary Tables S3 and S4). For a BMI of 22.5-24.99 kg/m^2, ≥ 100 excess MET-hours per week vs < 5 excess MET-hours per week was associated with 2.0 (95% CI: 1.8 to 2.2) percentage points lower body fat in men and 1.9 (95% CI: 1.6 to 2.0) percentage points lower body fat in women. For both men and women, within each stratum of BMI, the mean BMI was very similar across the categories of physical activity.

When we further adjusted for reported intakes of fruit and vegetables, and red and processed meats, or restricted the analysis to those who did not have an active job or those who had a university or college degree, the results were not materially altered. Comparing those doing ≥ 100 excess MET-hours per week to those doing < 5 excess MET-hours per week, body fat percentage was, on average 1.6 (95% CI: 1.5 to 1.7) percentage points lower for men and 1.4 (95% CI: 1.3 to 1.5) percentage points lower for women after adjustment for diet quality; 1.7 (95% CI: 1.6 to 1.9) percentage points lower for men and 1.6 (95% CI: 1.4 to 1.8) percentage points lower for women when restricting analyses to those who had a university or college

degree; and 1.6 (95% CI: 1.5 to 1.7) percentage points lower for men and 1.4 (95% CI: 1.3 to 1.5) percentage points lower for women when we restricted analyses to those who did not have a standing or manual job.

In men, the mean BMI was similar across 5-year age categories however the mean body fat percentage was higher in older age groups. In women, the mean BMI by 5-year age categories was slightly higher in older age groups, and the mean body fat percentage was also higher in older age groups (Supplementary Table S5). The association between BMI and body fat percentage was similar in each age decade (Supplementary Figures S1, S2, and S3). The differences in BMI between the extreme categories of physical activity were slightly larger and the differences in body fat percentage were slightly smaller with older age (Supplementary Figures S4, S5 and S6).

DISCUSSION

In this large sample of middle-aged British men and women, more physical activity was associated with both a lower BMI and a lower body fat percentage, although even men and women who did the most physical activity were, on average, overweight. More physical activity was also associated with a lower body fat percentage within each category of BMI, with an average 1-2 percentage points lower body fat in the most active, compared to the least active individuals. Most of the difference in body fat percentage with physical activity was between the very low and moderately-high levels of physical activity (<5 and 35-49.9 excess MET-hours per week, respectively); there was relatively little difference in body fat percentage between moderately-high and very high levels of physical activity (35-49.9 and ≥100 excess MET-hours per week, respectively).

The current study is large, and height and weight were measured by trained staff using standardised techniques. We examined whether important lifestyle factors (diet quality, education, and job type) which varied by physical activity level might modify the associations between physical activity, BMI and body fat percentage. In each of these sensitivity analyses, the results were essentially unchanged, although because this is an observational study we cannot rule out confounding by other factors. A limitation of the study is that physical activity was self-reported. Analysis of the sub-sample who had a repeat measurement of physical activity approximately 5 years after baseline indicates approximately 50% regression to the mean, which represents both the error in reporting physical activity and true changes in physical activity over time. The likely consequence of regression to the mean in physical activity levels over time is bias of associations towards the null, so that the true association between physical activity and body composition measures is likely to be stronger than that observed in this study. Participants were not given any specific instructions prior to body fat measurement. Hydration status, exercise and food consumption can have small effects on body fat values measured by bioimpedance; had these factors been standardised between participants, we may have seen slightly stronger associations between body fat percentage and physical activity. The study is cross-sectional, and therefore we can only show associations between reported physical activity and contemporaneous body composition. We cannot infer cause and effect: lower levels of physical activity may lead to greater adiposity, but it is also possible that increased adiposity leads to less physical activity.

Small studies (n~500) in young adults have shown that, for a given BMI, athletes have a lower body fat percentage than non-athletes (6, 7). These findings are, however, of limited relevance to older adults in the general population, who experience the highest burden of obesity-related disease. An analysis of 466,605 participants in the China Kadoorie Biobank, aged 30-79 years, found relatively weak associations between physical activity and either BMI or body fat percentage: a difference of approximately 100 total MET-hours per week was associated with 0.15 kg/m^2 lower BMI, and 0.48 percentage points lower body fat (13). Participants in China Kadoorie Biobank differed from those in UK Biobank in ethnicity and lifestyle, and also had a lower average BMI (23.4 (SD 3.2) kg/m^2 in men; 23.8 (SD 3.4) kg/m^2 in women). Their physical activity levels were comparable to the middle to upper range of physical activity of UK Biobank participants, and in this range we also saw only a small difference in body fat percentage.

Variation in BMI in the general population is largely due to differences in body fatness, but by definition it incorporates both adipose and lean body mass, and it is therefore difficult to disentangle the roles of adipose and lean mass in associations of BMI with health outcomes. For example, a higher BMI is an established risk factor for post-menopausal breast cancer, and probably increases risk through higher circulating sex hormones produced by the enzyme aromatase in the adipose tissue from precursor androgens (14). Several cohort studies have also shown that more physical activity is associated with a reduced risk of post-menopausal breast cancer, even after adjustment for BMI, and this finding is often taken as evidence that physical activity is independent of adiposity as a risk factor for post-menopausal breast cancer (15). Our results suggest, however, that adjustment for BMI may not have fully controlled for adiposity in these analyses.

In conclusion, in this sample of middle-aged British adults who were free from self-reported long-standing illness, men and women who reported doing the most physical activity had a lower BMI and a lower body fat percentage than those who reported doing the least physical activity. We also report new evidence that, for a given BMI, men and women who reported doing more physical activity had a lower body fat percentage; the greatest difference was observed between low and moderate levels of physical activity. BMI incorporates both adipose and lean mass, but is most strongly related to adiposity, and consequently is associated with morbidity and mortality from a wide range of diseases. However, to disentangle the possible effects of physical activity and adiposity on disease risk, future research should focus on more specific measures of adiposity.

Competing interests: All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

Contributorship: KEB and TJK conceived the research, KEB performed the statistical analyses; BJC contributed to the statistical methodology; MEGA contributed to generation of the physical activity variables. KEB, WG, BJC, MEGA, and TJK interpreted the data, drafted and reviewed the article for important intellectual content, KEB has primary responsibility for the final content. All authors read and approved the final manuscript. KEB is the guarantor for the study. This research has been conducted using the UK Biobank Resource.

Ethics approval: UK Biobank has ethical approval from the North West Multi-centre Research Ethics Committee. Participants gave informed consent on the touchscreen before taking part.

Funding: The authors are supported by Girdlers' New Zealand Health Research Council Fellowship (KEB), Cancer Research UK (TJK; C8221/A19170 and 570/A16491), the BHF Centre of Research Excellence, Oxford (BJC; BHF no. RE/13/1/30181), the UK Medical Research Council (MEGA, and TJK; MR/M012190/1), and the Clarendon Fund and US-UK Fulbright Commission (WG). The funders did not influence the conduct of the study, analysis or interpretation of the data, the writing of this report, or the decision to publish. The authors had full access to all the data in the study, can take responsibility for the integrity of the data, and the accuracy of the data analysis.

Data sharing: UK Biobank is an open access resource. Bona fide researchers can apply to use the UK Biobank dataset by registering and applying at

http://www.ukbiobank.ac.uk/register-apply/. Statistical code for used for this manuscript is available to other researchers on request by emailing Kathryn Bradbury (kathryn.bradbury@ceu.ox.ac.uk).

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Table1 Characteristics of men participating in UK Biobank by physical activity

	Low activity < 10 excess MET-hours/wk[1] *n* = 26,405	Moderate activity 10-49.9 excess MET-hours/wk[1] *n* = 63,022	High activity ≥ 50 excess MET-hours/wk[1] *n* = 29,803	All men *n* = 119,230
Age (years)				
Mean (SD)	55.3 (8.0)	55.7 (8.4)	56.0 (8.4)	55.7 (8.3)
White ethnicity[a]	24,741 (93.7)	59,842 (95.0)	28,468 (95.5)	113,051 (94.8)
Socioeconomic status[b]				
Upper fifth	6,274 (23.8)	14,701 (23.4)	5,867 (19.7)	26,842 (22.5)
Qualifications[c]				
College or University degree/vocational qualification	18,878 (71.5)	45,453 (72.2)	17,731 (59.5)	82,062 (68.8)
BMI (kg/m^2)[d]				
Mean (SD)	28.0 (4.2)	27.1 (3.7)	27.1 (3.6)	27.3 (3.8)
< 20.00	238 (0.9)	559 (0.9)	289 (1.0)	1,086 (0.9)
20.00-24.99	5,849 (22.2)	17,425 (27.7)	8,326 (28.0)	31,600 (26.6)

25.00-29.99	13,220 (50.2)	32,745 (52.1)	15,403 (51.8)	61,368 (51.6)
≥ 30.00-34.99	7,015 (26.7)	12,135 (19.3)	5,699 (19.2)	24,849 (20.9)
Body fat (%)[e]				
Mean (SD)	25.8 (5.5)	24.2 (5.4)	23.6 (5.5)	24.4 (5.5)
< 15.00	761 (2.9)	3,062 (4.9)	1,945 (6.6)	5,768 (4.9)
15.00-19.99	2,810 (10.8)	9,714 (15.6)	5,148 (17.5)	17,672 (15.0)
20.00-24.99	7,714 (29.6)	21,023 (33.7)	10,080 (34.3)	38,817 (32.9)
25.00-29.99	9,194 (35.2)	19,816 (31.8)	8,686 (29.5)	37,696 (32.0)
≥ 30.00	5,629 (21.6)	8,703 (14.0)	3,558 (12.1)	17,890 (15.2)
Height (m)[f]				
< 1.70	3,902 (14.8)	9,251 (14.7)	5,467 (18.4)	18,620 (15.7)
1.70 - 1.74	6,250 (23.8)	15,301 (24.4)	7,917 (26.6)	29,468 (24.8)
1.75 - 1.79	7,738 (29.4)	18,182 (28.9)	8,246 (27.8)	34,166 (28.7)
1.80 - 1.84	5,308 (20.2)	12,992 (20.7)	5,408 (18.2)	23,708 (19.9)
≥ 1.85	3,115 (11.8)	7,120 (11.3)	2,682 (9.0)	12,917 (10.9)
Mean (SD) excess MET-hours per week[g]	5.1 (2.9)	25.8 (11.0)	92.9 (43.3)	38.0 (40.1)
Standing or walking job[h]	2,524 (12.7)	9,766 (23.1)	12,961 (65.4)	25,251 (30.8)

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Manual job[i]	561 (2.8)	3,214 (7.6)	8,145 (41.1)	11,920 (14.6)
Smoking status[1j]				
Never	14,269 (54.0)	34,209 (54.3)	15,101 (50.7)	63,579 (53.3)
Previous	8,866 (33.6)	22,438 (35.6)	10,936 (36.7)	42,240 (35.4)
Current	3,215 (12.2)	6,252 (9.9)	3,680 (12.4)	13,147 (11.0)
Alcohol consumption[k]				
Three or more times a week	14,391 (54.5)	36,542 (58.0)	15,477 (52.0)	66,410 (55.8)
Fruit and vegetable consumption[l]				
< 3.00 servings per day	8,754 (33.2)	14,052 (22.3)	5,966 (20.0)	28,772 (24.1)
3.00-3.99 servings per day	6,031 (22.8)	13,370 (21.2)	5,204 (17.5)	24,605 (20.6)
4.00-4.99 servings per day	4,619 (17.5)	12,622 (20.0)	5,485 (18.4)	22,726 (19.1)
5.00-5.99 servings per day	2,926 (11.1)	8,930 (14.2)	4,389 (14.7)	16,245 (13.6)
≥ 6.00 servings per day	3,798 (14.4)	13,559 (21.5)	8,405 (28.2)	25,762 (21.6)
Total red and processed meat consumption[m]				
< 2.00 times per week	2,120 (8.0)	5,838 (9.3)	2,956 (9.9)	10,914 (9.2)
2.00-2.99 times a week	6,291 (23.8)	16,042 (25.5)	7,170 (24.1)	29,503 (24.7)
3.00-3.99 times a week	3,927 (14.9)	9,323 (14.8)	4,186 (14.1)	17,436 (14.6)

4.00-4.99 times a week	4,866 (18.4)	10,990 (17.4)	5,069 (17.0)	20,925 (17.6)
≥ 5.00 times a week	9,042 (34.2)	20,523 (32.6)	10,229 (34.3)	39,794 (33.4)

Values are number (%) unless otherwise stated

Number of participants with missing data (the total number participants who have missing data, or who reported ‘do not know’ or ‘prefer not to answer’) for each characteristic is as follows: 0 for age, 377 for ethnicity, 159 for socioeconomic status, 705 for qualifications, 327 for BMI, 1,367 for body fat %, 351 for height, 0 for excess MET-hours/wk, 57 for standing or walking job, 38 for manual job, 264 for smoking status, 35 for alcohol consumption, 1,120 for fruit and vegetable consumption, 658 for total red and processed meat consumption

[a]Participants who reported their ethnicity as ‘White’, ‘British’, ‘Irish’, or ‘Any other white background’

[b]We generated quintiles of socioeconmic status based on the Townsend deprivation index for the whole cohort (UK Biobank variable n_189_0_0)

[c]Vocational qualifications defined as other professional qualification (eg: nursing or teaching)/ National Vocational Qualification or Higher National Diploma or Higher National Certificate) (touchscreen question number D12, UK Biobank variable n_6138_0_0)

[d]We preferentially used BMI derived from height and weight measured during the impedance measurement (UK Biobank variable n_23104_0_0_), but if missing used the body size measures (UK Biobank variable n_21001_0_0); both of these are direct measures of height and weight made on the same day at the assessment centre

[e]Body fat % (UK Biobank variable n_23099_0_0)

[f]Standing height (UK Biobank variable n_50_0_0)

[g]Excess MET-hours/wk estimated from the combination of reported walking, moderate and vigorous physical activity (for details see methods text)

[h]Participants who reported their work 'usually' or 'always' involved walking or standing for most of the time (touchscreen question number D9B, UK Biobank variable n_806_0_0)

[i]Participants who reported their work 'usually' or 'always' involved heavy manual or physical work for most of the time (touchscreen question number D9C, UK Biobank variable n_816_0_0)

[j]Smoking status (UK Biobank variable n_20116_0_0)

[k]Participants who reported consuming alcohol three to four times per week or daily or almost daily (touchscreen question number A1, UK Biobank variable n_1558_0_0)

[l]Total fruit and vegetable consumption is the sum of fresh fruit intake (touchscreen question number DT3, UK Biobank variable n_1309_0_0), cooked vegetable intake (touchscreen question numbers DT1, UK Biobank variable n_1289_0_0) and raw vegetable intake (touchscreen question number DT1, and UK Biobank variable n_1299_0_0). To sum the frequencies, 'Less than one' was coded as 0.5, and we coded 1 piece of fresh fruit as a serving and 2 tablespoons of vegetables as a serving.

[m]Total red and processed meat consumption is the sum of processed meat (touchscreen question number DT8 and UK Biobank variable n_1349_0_0), beef (touchscreen question number DT7 and UK Biobank variable n_1369_0_0), lamb/mutton (touchscreen question number DT7A and UK Biobank variable n_1379_0_0) , and pork (touchscreen question number DT7B and UK Biobank variable n_1389) intake. To sum the frequencies, we used the following coding: 'Never' = 0, 'Less than once a week' = 0.5, 'Once a week' = 1, '2-4 times a week' = 3, '5-6 times a week' = 5.5, 'Once or more daily' = 7.

Table 2 Characteristics of women participating in UK Biobank by physical activity

	Low activity < 10 excess MET-hours/wk[1] n = 31,931	Moderate activity 10-49.9 excess MET-hours/wk[1] n = 78,171	High activity ≥ 50 excess MET-hours/wk[1] n = 30,476	All women n = 140,578
Age (years)				
Mean (SD)	54.6 (7.8)	55.2 (8.1)	56.2 (8.1)	55.3 (8.1)
White ethnicity[a]	30,164 (94.5)	74,471 (95.3)	29,088 (95.5)	133,723 (95.1)
Socioeconomic status[b]				
Upper fifth	6,956 (21.8)	17,177 (22.0)	6,407 (21.0)	30,540 (21.8)
Qualifications[c]				
College or University degree/vocational qualification	19,320 (60.5)	49,219 (62.9)	17,826 (58.5)	86,365 (61.5)
BMI (kg/m^2)[d]				
Mean (SD)	27.2 (5.1)	26.0 (4.4)	25.7 (4.2)	26.2 (4.6)
< 20.00	954 (3.0)	2,838 (3.6)	1,270 (4.2)	5,062 (3.6)

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20.00-24.99	10,930 (34.3)	33,256 (42.7)	13,749 (45.2)	57,935 (41.3)
25.00-29.99	12,037 (37.8)	29,041 (37.2)	11,062 (36.4)	52,140 (37.2)
≥ 30.00-34.99	7,930 (24.9)	12,839 (16.5)	4,334 (14.3)	25,103 (17.9)
Body fat (%)[e]				
Mean (SD)	37.1 (6.6)	35.2 (6.5)	34.4 (6.6)	35.5 (6.7)
< 25.00	1,197 (3.8)	4,842 (6.3)	2,524 (8.4)	8,563 (6.2)
25.00-29.99	3,256 (10.3)	11,220 (14.5)	4,920 (16.3)	19,396 (14.0)
30.00-34.99	7,011 (22.2)	20,467 (26.5)	8,224 (27.3)	35.702 (25.7)
35.00-39.99	9,129 (29.0)	22,181 (28.7)	8,347 (27.7)	39,657 (28.6)
≥ 40.00	10,940 (34.7)	18,506 (24.0)	6,110 (20.3)	35,556 (25.6)
Height (m)[f]				
< 1.55	2,758 (8.7)	6,315 (8.1)	2,810 (9.2)	11,883 (8.5)
1.55 - 1.59	6,268 (19.7)	15,551 (19.9)	6,504 (21.4)	28,323 (20.2)
1.60 - 1.64	10,067 (31.6)	24,437 (31.3)	9,631 (31.7)	44,135 (31.5)
1.65 - 1.69	7,993 (25.1)	20,091 (25.8)	7,530 (24.8)	35,614 (25.4)
≥ 1.70	4,779 (15.0)	11,621 (14.9)	3,952 (13.0)	20,352 (14.5)
Mean (SD) excess MET-hours per week[g]	5.3 (2.8)	25.5 (10.9)	83.0 (33.3)	33.4 (32.5)

Standing or walking job[h]	3,901 (17.4)	12,349 (25.7)	9,593 (56.3)	25,843 (29.53)
Manual job[i]	521 (2.3)	2,576 (5.4)	3,883 (22.8)	6,980 (8.0)
Smoking status[j]				
Never	19,513 (61.1)	47,974 (61.4)	18,370 (60.3)	85,857 (61.1)
Previous	9,468 (29.7)	24,366 (31.2)	9,635 (31.6)	43,469 (30.9)
Current	2,883 (9.0)	5,661 (7.2)	2,417 (7.9)	10,961 (7.8)
Alcohol consumption[k]				
Three or more times a week	12,670 (39.7)	33,747 (43.2)	12,137 (39.8)	58,554 (41.7)
Fruit and vegetable consumption[l]				
< 3.00 servings per day	6,601 (20.7)	9,849 (12.6)	3,070 (10.1)	19,520 (13.9)
3.00-3.99 servings per day	6,507 (20.4)	13,485 (17.3)	4,232 (13.9)	24,224 (17.2)
4.00-4.99 servings per day	6,672 (20.9)	16,489 (21.1)	5,701 (18.7)	28,862 (20.5)
5.00-5.99 servings per day	5,092 (16.0)	14,460 (18.5)	5,573 (18.3)	25,125 (17.9)
≥ 6.00 servings per day	6,874 (21.5)	23,557 (30.1)	11,740 (38.5)	42,171 (30.0)
Total red and processed meat consumption[m]				
< 2.00 times per week	5,462 (17.1)	15,254 (19.5)	6,729 (22.1)	27,445 (19.5)
2.00-2.99 times a week	10,903 (34.2)	27,329 (35.0)	10,190 (33.4)	48,422 (34.4)

3.00-3.99 times a week	5,395 (16.9)	12,642 (16.2)	4,823 (15.8)	22,860 (16.3)
4.00-4.99 times a week	4,058 (12.7)	9,143 (11.7)	3,423 (11.2)	16,624 (11.8)
≥ 5.00 times a week	5,973 (18.7)	13,456 (17.2)	5,144 (16.9)	24,573 (17.5)

Values are number (%) unless otherwise stated

Number of participants with missing data (the total number participants who have missing data, or who reported ‘do not know’ or ‘prefer not to answer’) for each characteristic is as follows: 0 for age, 263 for ethnicity, 150 for socioeconomic status, 756 for qualifications, 338 for BMI, 1,704 for body fat %, 271 for height, 0 for excess MET-hours/wk, 64 for standing or walking job, 52 for manual job, 291 for smoking status, 44 for alcohol consumption, 676 for fruit and vegetable consumption, 655 for total red and processed meat consumption

[a]Participants who reported their ethnicity as ‘White’, ‘British’, ‘Irish’, or ‘Any other white background’

[b]We generated quintiles of socioeconmic status based on the Townsend deprivation index for the whole cohort (UK Biobank variable n_189_0_0)

[c]Vocational qualifications defined as other professional qualification (eg: nursing or teaching)/ National Vocational Qualification or Higher National Diploma or Higher National Certificate) (touchscreen question number D12, UK Biobank variable n_6138_0_0)

[d]We preferentially used BMI derived from height and weight measured during the impedance measurement (UK Biobank variable n_23104_0_0_), but if missing used the body size measures (UK Biobank variable n_21001_0_0); both of these are direct measures of height and weight made on the same day at the assessment centre.

[e]Body fat % (UK Biobank variable n_23099_0_0)

[f]Standing height (UK Biobank variable n_50_0_0)

[g]Excess MET-hours/wk estimated from the combination of reported walking, moderate and vigorous physical activity (for details see methods text)

[h]Participants who reported their work 'usually' or 'always' involved walking or standing for most of the time (touchscreen question number D9B, UK Biobank variable n_806_0_0)

[i]Participants who reported their work 'usually' or 'always' involved heavy manual or physical work for most of the time (touchscreen question number D9C, UK Biobank variable n_816_0_0)

[j]Smoking status (UK Biobank variable n_20116_0_0)

[k]Participants who reported consuming alcohol three to four times per week or daily or almost daily (touchscreen question number A1, UK Biobank variable n_1558_0_0)

[l]Total fruit and vegetable consumption is the sum of fresh fruit intake (touchscreen question number DT3, UK Biobank variable n_1309_0_0), cooked vegetable intake (touchscreen question numbers DT1, UK Biobank variable n_1289_0_0) and raw vegetable intake (touchscreen question number DT1, and UK Biobank variable n_1299_0_0). To sum the frequencies, 'Less than one' was coded as 0.5, and we coded 1 piece of fresh fruit as a serving and 2 tablespoons of vegetables as a serving.

[m]Total red and processed meat consumption is the sum of processed meat (touchscreen question number DT8 and UK Biobank variable n_1349_0_0), beef (touchscreen question number DT7 and UK Biobank variable n_1369_0_0), lamb/mutton (touchscreen question number DT7A and UK Biobank variable n_1379_0_0) , and pork (touchscreen question number DT7B and UK Biobank variable n_1389) intake. To sum the frequencies, we used the following coding: 'Never' = 0, 'Less than once a week' = 0.5, 'Once a week' = 1, '2-4 times a week' = 3, '5-6 times a week' = 5.5, 'Once or more daily' = 7.

Figure legends

Figure 1 UK Biobank participant flow diagram

MPA: moderate physical activity; VPA: vigorous physical activity

Figure 2 Body fat percentage by BMI in UK Biobank

Values are mean body fat % by single-unit BMI categories

Adjusted for age (5 year categories)

Error bars represent 1 SD either side of the mean

Estimates shown for cells with 200 or more participants

Figure 3 Mean BMI and body fat percentage by physical activity in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat % by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Adjusted for age (5 year categories)

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

Figure 4 Mean body fat percentage by physical activity, stratified by BMI category in UK Biobank

Panel A: men; Panel B: women

Values are mean body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Estimates shown for cells with 200 or more participants

Adjusted for age (5 year categories)

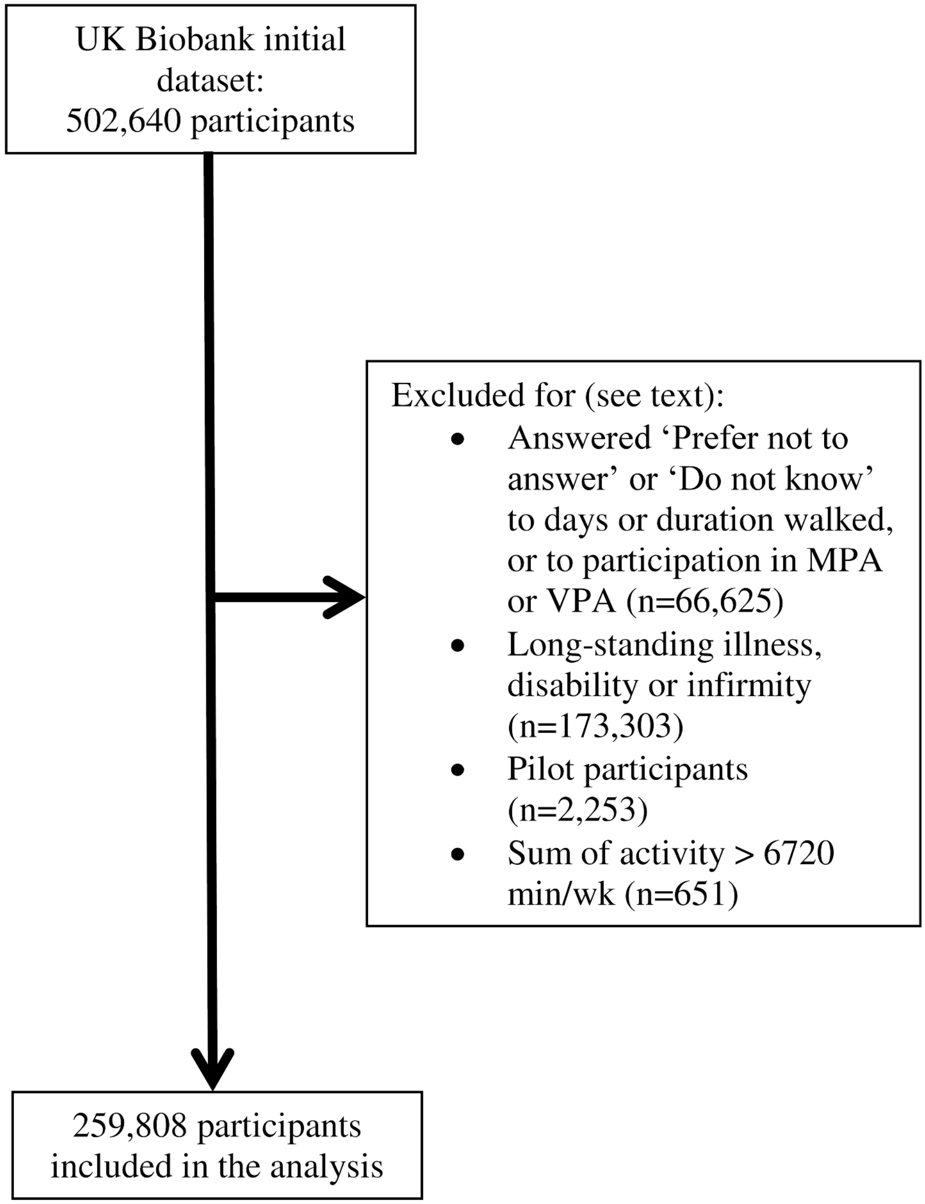

Figure 1 UK Biobank participant flow diagram
MPA: moderate physical activity; VPA: vigorous physical activity

131x171mm (600 x 600 DPI)

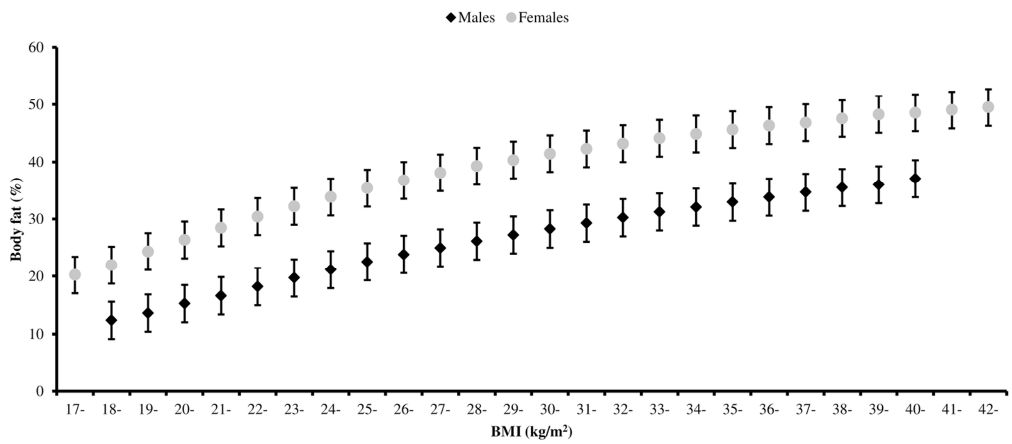

Figure 2 Body fat percentage by BMI in UK Biobank
Values are mean body fat % by single-unit BMI categories
Adjusted for age (5 year categories)
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

67x29mm (600 x 600 DPI)

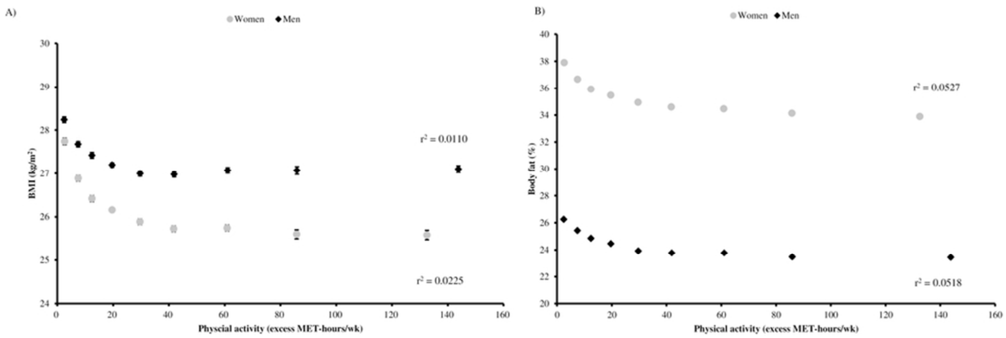

Figure 3 Mean BMI and body fat percentage by physical activity in UK Biobank
Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat % by physical activity (excess MET-hrs/wk)
Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Adjusted for age (5 year categories)
Errors bars are 95% CI

81x26mm (300 x 300 DPI)

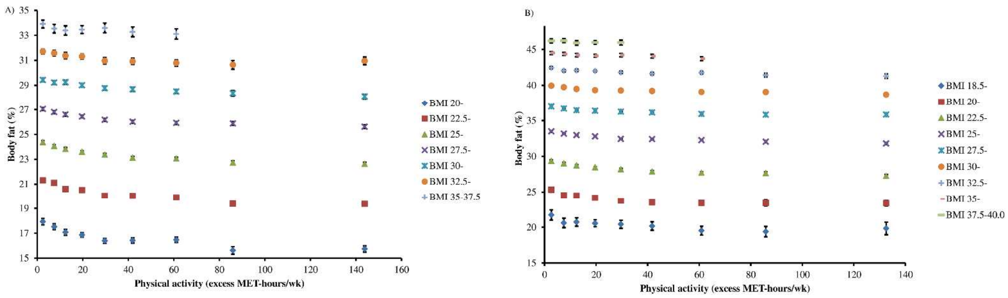

Figure 4 Mean body fat percentage by physical activity, stratified by BMI category in UK Biobank
Panel A: men; Panel B: women
Values are mean body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Estimates shown for cells with 200 or more participants
Adjusted for age (5 year categories)

4095x1181mm (72 x 72 DPI)

Table S1 Repeated measures of physical activity in men who completed the repeat assessment visit in UK Biobank 5 years after recruitment

	Physical activity (excess MET-hours per week)[a]								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥100
	All men (n = 119,230)								
Number of men	*12,613*	*13,792*	*12,381*	*20,983*	*15,023*	*14,635*	*13,415*	*7,043*	[illegible]
Baseline[b]	2.5	7.5	12.4	19.7	29.7	41.9	61.1	85.9	[illegible]
	Men who completed the repeat assessment visit (n = 5,158)								
Number of men	*602*	*614*	*534*	*943*	*691*	*631*	*541*	*279*	[illegible]
Baseline[b]	2.6	7.6	12.4	19.7	29.8	42.1	60.5	85.6	[illegible]
Repeat[b]	12.2	16.3	20.8	26.1	32.2	40.3	47.9	60.5	[illegible]

[a]Categories are defined from baseline data

[b]Values are mean excess MET-hours per week

Table S2 Repeated measures of physical activity in women who completed the repeat assessment visit in UK Biobank 5 years after recruitment

	Physical activity (excess MET-hours per week)[a]								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	[illegible]
	All women (n = 140,578)								
Number of women	*14,299*	*17,632*	*15,970*	*26,156*	*18,555*	*17,490*	*16,231*	*7,407*	[illegible]
Baseline[b]	2.6	7.5	12.4	19.6	29.6	41.7	60.9	85.8	[illegible]
	Women who completed the repeat assessment visit (n = 5,067)								
Number of women	*515*	*659*	*606*	*1,004*	*681*	*640*	*555*	*229*	*178*
Baseline[b]	2.6	7.6	12.3	19.6	29.7	41.7	61.0	85.0	[illegible]
Repeat[b]	11.9	18.5	21.3	26.1	33.2	40.6	52.8	59.2	[illegible]

[a]Categories are defined from baseline data

[b]Values are mean excess MET-hours per week

Table S3 Mean (95% CI) body fat percentage by categories of BMI and physical activity in men in UK Biobank.

Categories of BMI	Categories of physical activity (MET-hours/wk)								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
20-	16.6 (16.3-16.8) *n = 649*	16.1 (15.9-16.4) *n = 780*	15.7 (15.4-15.9) *n = 743*	15.4 (15.3-15.6) *n = 1356*	14.9 (14.7-15.1) *n = 1014*	15.0 (14.7-15.2) *n = 986*	15.0 (14.8-15.2) *n = 1940*	14.1 (13.8-14.4) *n = 478*	14.3 (14.0-14.6) *n = 658*
Mean BMI	*21.6*	*21.5*	*21.5*	*21.5*	*21.5*	*21.5*	*21.6*	*21.5*	*21.5*
22.5-	19.9 (19.8-20.1) *n = 1943*	19.7 (19.6-19.8) *n = 2477*	19.2 (19.0-19.3) *n = 2411*	19.1 (19.0-19.2) *n = 4289*	18.6 (18.5-18.7) *n = 3379*	18.6 (18.4-18.7) *n = 3247*	18.4 (18.3-18.6) *n = 2851*	17.9 (17.7-18.1) *n = 1490*	17.9 (17.8-18.1) *n = 1909*
Mean BMI	*23.9*	*23.9*	*23.9*	*23.9*	*23.9*	*23.9*	*23.8*	*23.9*	*23.8*
25-	23.0 (22.9-23.1) *n = 3217*	22.7 (22.6-22.8) *n = 3861*	22.4 (22.3-22.5) *n = 3606*	22.2 (22.1-22.3) *n = 6180*	21.9 (21.8-22.0) *n = 4428*	21.7 (21.6-21.8) *n = 4419*	21.6 (21.5-21.7) *n = 3960*	21.3 (21.1-21.4) *n = 2095*	21.2 (21.1-21.3) *n = 2694*
Mean BMI	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*
27.5-	25.7 (25.6-25.8) *n = 2950*	25.4 (25.3-25.5) *n = 3192*	25.2 (25.1-25.3) *n = 2793*	25.0 (24.9-25.1) *n = 4818*	24.7 (24.6-24.9) *n = 3302*	24.6 (24.4-24.7) *n = 3199*	24.5 (24.3-24.6) *n = 2948*	24.4 (24.2-24.6) *n = 1561*	24.2 (24.0-24.3) *n = 2145*
Mean BMI	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*
30-	28.1 (27.9-28.2) *n = 1867*	27.8 (27.7-28.0) *n = 1780*	27.8 (27.7-28.0) *n = 1498*	27.6 (27.4-27.7) *n = 2409*	27.3 (27.2-27.5) *n = 1644*	27.2 (27.1-27.4) *n = 1585*	27.1 (26.9-27.2) *n = 1560*	26.9 (26.7-27.1) *n = 809*	26.7 (26.5-26.9) *n = 1107*
Mean BMI	*31.1*	*31.1*	*31.1*	*31.0*	*31.0*	*31.0*	*31.0*	*31.0*	*31.0*
32.5-	30.4 (30.2-30.6) *n = 984*	30.2 (30.0-30.4) *n = 873*	30.0 (29.7-30.2) *n = 663*	29.9 (29.7-30.1) *n = 1009*	29.5 (29.3-29.8) *n = 654*	29.5 (29.2-29.7) *n = 634*	29.3 (29.1-29.6) *n = 614*	29.2 (28.8-29.6) *n = 335*	29.5 (29.2-29.8) *n = 440*
Mean BMI	*33.6*	*33.6*	*33.5*	*33.5*	*33.4*	*33.5*	*33.5*	*33.5*	*33.5*

35-	32.5 (32.2-32.9) *n = 428*	32.1 (31.8-32.5) *n = 358*	32.0 (31.6-32.4) *n = 302*	32.0 (31.7-32.3) *n = 416*	32.2 (31.8-32.5) *n = 280*	31.8 (31.4-32.2) *n = 261*	31.7 (31.3-32.1) *n = 247*	-	-
Mean BMI	*36.1*	*36.0*	*36.0*	*36.0*	*36.0*	*36.0*	*36.0*		
37.5-	34.3 (33.9-34.8) *n = 217*	-	-	-	-	-		-	-
Mean BMI	*38.5*								

Adjusted for age (5 year categories)
Values not shown for cells with less than 200 participants

Table S4 Mean (95% CI) body fat percentage by categories of BMI and physical activity in women in UK Biobank

Categories of BMI	Categories of physical activity (MET-hours/wk) <5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
18.5-	24.4 (24.0-24.8) *n = 313*	23.5 (23.2-23.9) *n = 460*	23.5 (23.2-23.8) *n = 405*	23.1 (22.9-23.4) *n = 749*	22.7 (22.4-23.0) *n = 569*	22.5 (22.2-22.7) *n = 556*	22.3 (2[illegible]-22.6) *n = [illegible]26*	22.3 (21.9-22.8) *n = 219*	22.3 (21.9-22.7) *n = 267*
Mean BMI	*19.4*	*19.3*	*19.4*	*19.4*	*19.4*	*19.4*	*19.4*	*19.3*	*19.4*
20-	28.4 (28.2-28.6) *n = 1657*	28.0 (27.9-28.2) *n = 2333*	27.8 (27.6-27.9) *n = 2378*	27.5 (27.4-27.6) *n = 4095*	27.2 (27.1-27.3) *n = 3115*	26.8 (26.7-27.0) *n = 3034*	26.7 (2[illegible]-26.8) *n = 2746*	26.6 (26.4-26.8) *n = 1327*	26.2 (26.0-26.4) *n = 1156*
Mean BMI	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*
22.5-	32.6 (32.4-32.7) *n = 2872*	32.2 (32.1-32.3) *n = 4068*	32.0 (31.9-32.1) *n = 4014*	31.8 (31.7-31.9) *n = 6819*	31.4 (31.3-31.5) *n = 4981*	31.4 (31.3-31.5) *n = 4820*	31.2 (31.1-31.3) *n = 4496*	31.0 (30.8-31.2) *n = 2026*	30.7 (30.6-30.9) *n = 1998*
Mean BMI	*23.8*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*
25-	36.0 (35.9-36.2) *n = 2953*	35.7 (35.6-35.8) *n = 4016*	35.4 (35.3-35.6) *n = 3594*	35.4 (35.3-35.5) *n = 6034*	35.2 (35.1-35.3) *n = 4288*	35.1 (35.0-35.2) *n = 4069*	34.9 (34.8-35.0) *n = 3705*	34.8 (34.6-35.0) *n = 1692*	34.8 (34.6-35.0) *n = 1516*
Mean BMI	*26.2*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*
27.5-	39.0 (38.9-39.2) *n = 2353*	38.8 (38.6-38.9) *n = 2715*	38.5 (38.4-38.7) *n = 2370*	38.3 (38.2-38.5) *n = 3704*	38.3 (38.2-38.4) *n = 2616*	38.2 (38.1-38.4) *n = 2366*	38.1 (37.9-38.2) *n = 2262*	38.0 (37.8-38.2) *n = 1008*	37.7 (37.5-37.9) *n = 879*
Mean BMI	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*
30-	41.5 (41.3-41.7) *n = 1625*	41.1 (40.9-41.3) *n = 1716*	41.1 (40.9-41.3) *n = 1424*	41.0 (40.9-41.2) *n = 2185*	40.8 (40.6-41.0) *n = 1366*	40.6 (40.4-40.8) *n = 1237*	40.8 (40.6-41.0) *n = 1181*	40.4 (40.1-40.7) *n = 564*	40.3 (40.0-40.6) *n = 468*
Mean BMI	*31.1*	*31.1*	*31.1*	*31.1*	*31.1*	*31.0*	*31.1*	*31.0*	*31.1*
32.5-	43.6	43.4	43.2	43.1	43.2	43.0	42.7	42.7	42.5

	(43.4-43.8)	(43.2-43.6)	(43.0-43.5)	(42.9-43.3)	(43.0-43.5)	(42.8-43.3)	(42.4-43.0)	(42.3-43.1)	(42.0-42.9)
	n = 1008	*n = 989*	*n = 774*	*n = 1149*	*n = 699*	*n = 651*	*n = 611*	*n = 260*	*n = 233*
Mean BMI	*33.6*	*33.6*	*33.6*	*33.6*	*33.6*	*33.5*	*33.5*	*33.5*	*33.5*
35-	45.3 (45.0-45.5) *n = 577*	45.2 (45.0-45.5) *n = 577*	44.9 (44.6-45.3) *n = 444*	45.0 (44.7-45.3) *n = 584*	44.9 (44.6-45.3) *n = 359*	44.9 (44.5-45.3) *n = 313*	44.8 (44.4-45.2) *n = 282*	-	-
Mean BMI	*36.1*	*36.1*	*36.0*	*36.1*	*36.1*	*36.1*	*36.0*		
37.5-	47.0 (46.6-47.3) *n = 368*	46.6 (46.2-47.0) *n = 303*	46.8 (46.3-47.2) *n = 207*	46.7 (46.3-47.1) *n = 316*	46.6 (46.1-47.0) *n = 205*	-	-	-	-
Mean BMI	*38.6*	*38.5*	*38.6*	*38.5*	*38.5*				
40-	48.3 (47.8-48.7) *n = 220*	-	-	-	-	-	-	-	-
Mean BMI	*41.1*								

Adjusted for age (5 year categories)

Values not shown for cells with less than 200 participants

Table S5 BMI and body fat percentage by sex and 5-year age category in UK Biobank

	n	BMI	Body fat percentage
Men			
< 45 years	15176	27.2 (4.0)	22.8 (5.5)
45-49 years	17569	27.4 (3.9)	23.5 (5.5)
50-54 years	18375	27.5 (3.9)	24.1 (5.5)
55-59 years	20580	27.3 (3.8)	24.6 (5.5)
60-64 years	26532	27.3 (3.7)	25.1 (5.4)
≥ 65 years	20671	27.1 (3.6)	25.6 (5.3)
Women			
< 45 years	17392	25.7 (4.8)	33.7 (7.0)
45-49 years	21848	26.0 (4.8)	34.3 (7.0)
50-54 years	23728	26.3 (4.7)	35.3 (6.7)
55-59 years	25329	26.3 (4.6)	35.9 (6.5)
60-64 years	31600	26.5 (4.4)	36.4 (6.3)
≥ 65 years	20343	26.5 (4.2)	36.7 (6.0)

Values are mean (SD)

Numbers of participants shown are for BMI within each age category, slightly fewer participants have information on body fat percentage

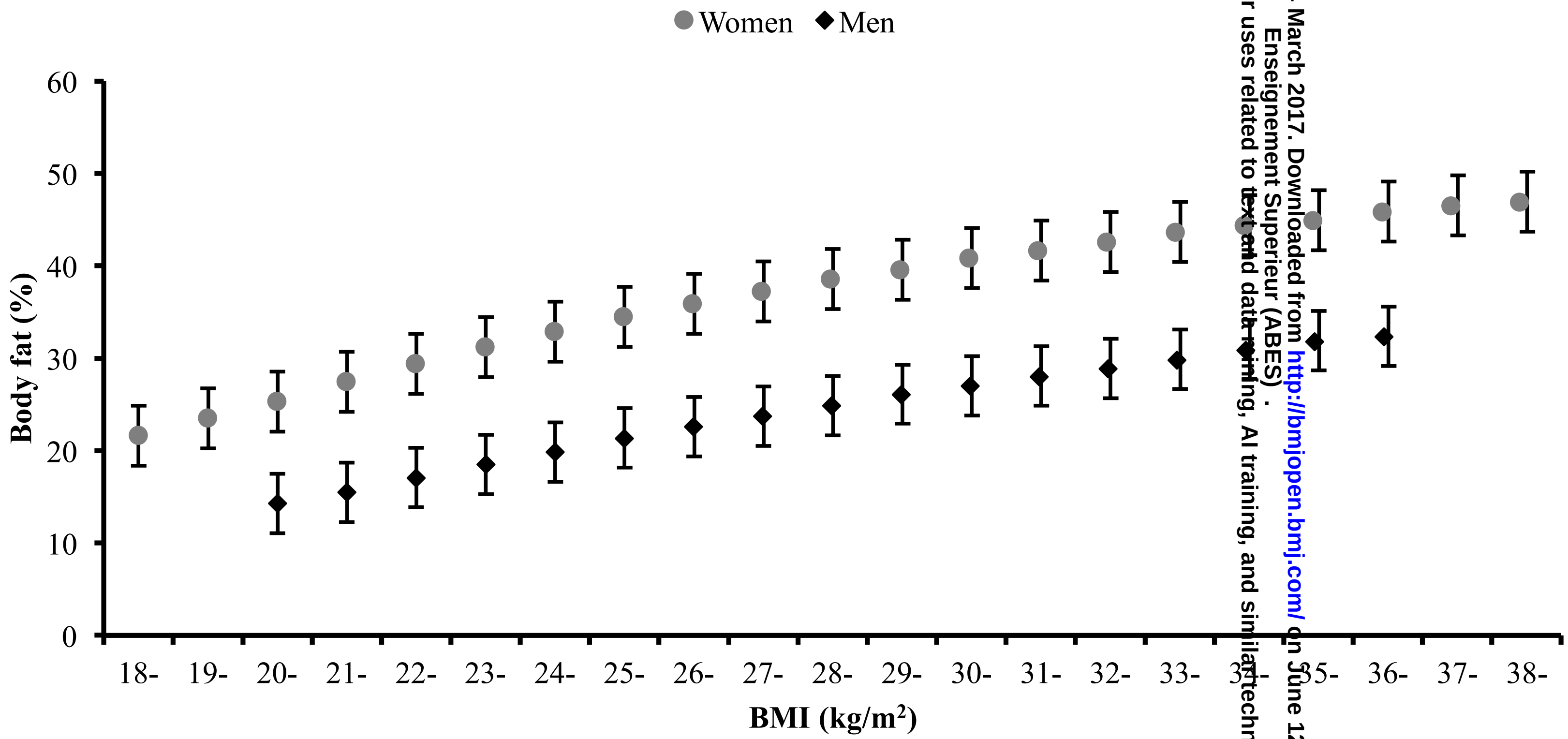

Figure S1 Body fat percentage by BMI for participants aged younger than 50 years in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

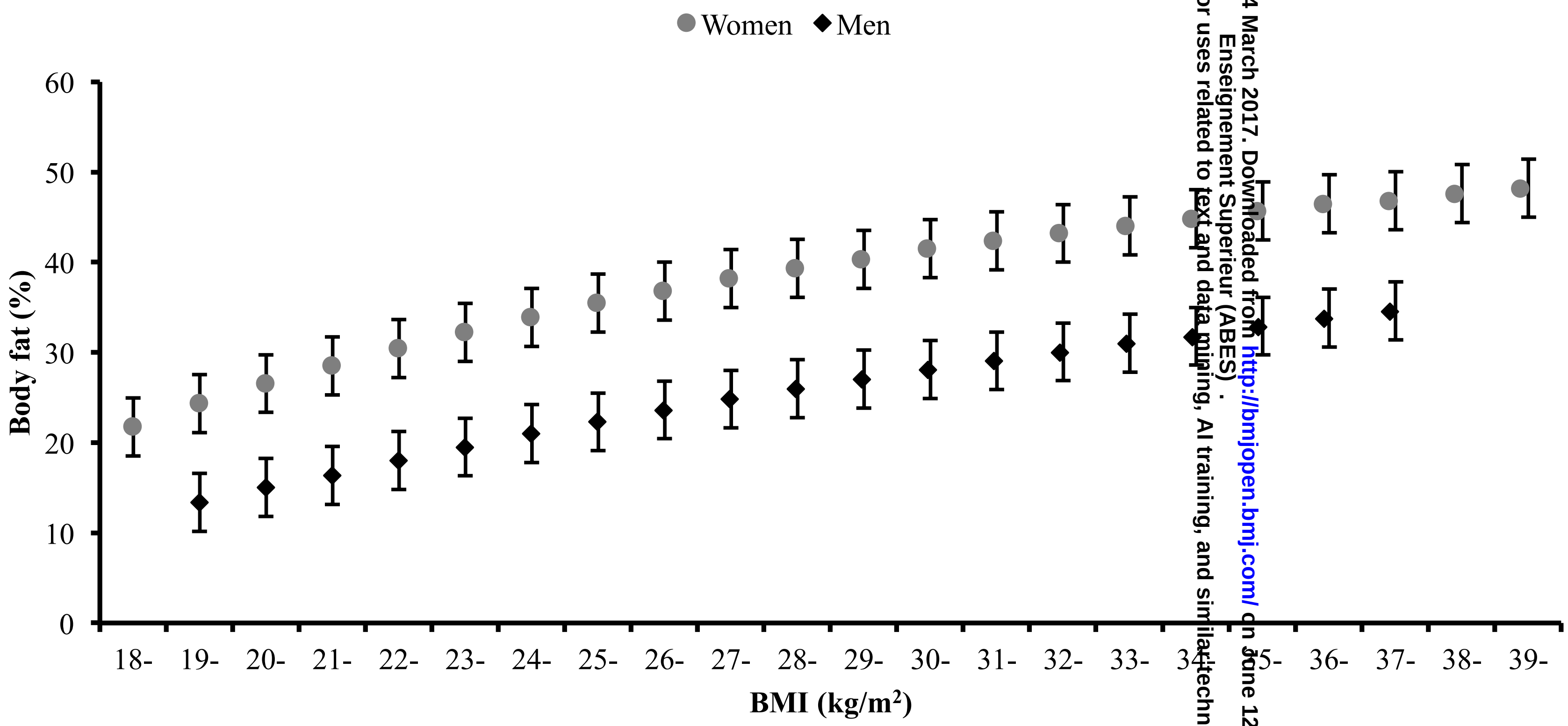

Figure S2 Body fat percentage by BMI for participants aged 50-59 years in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

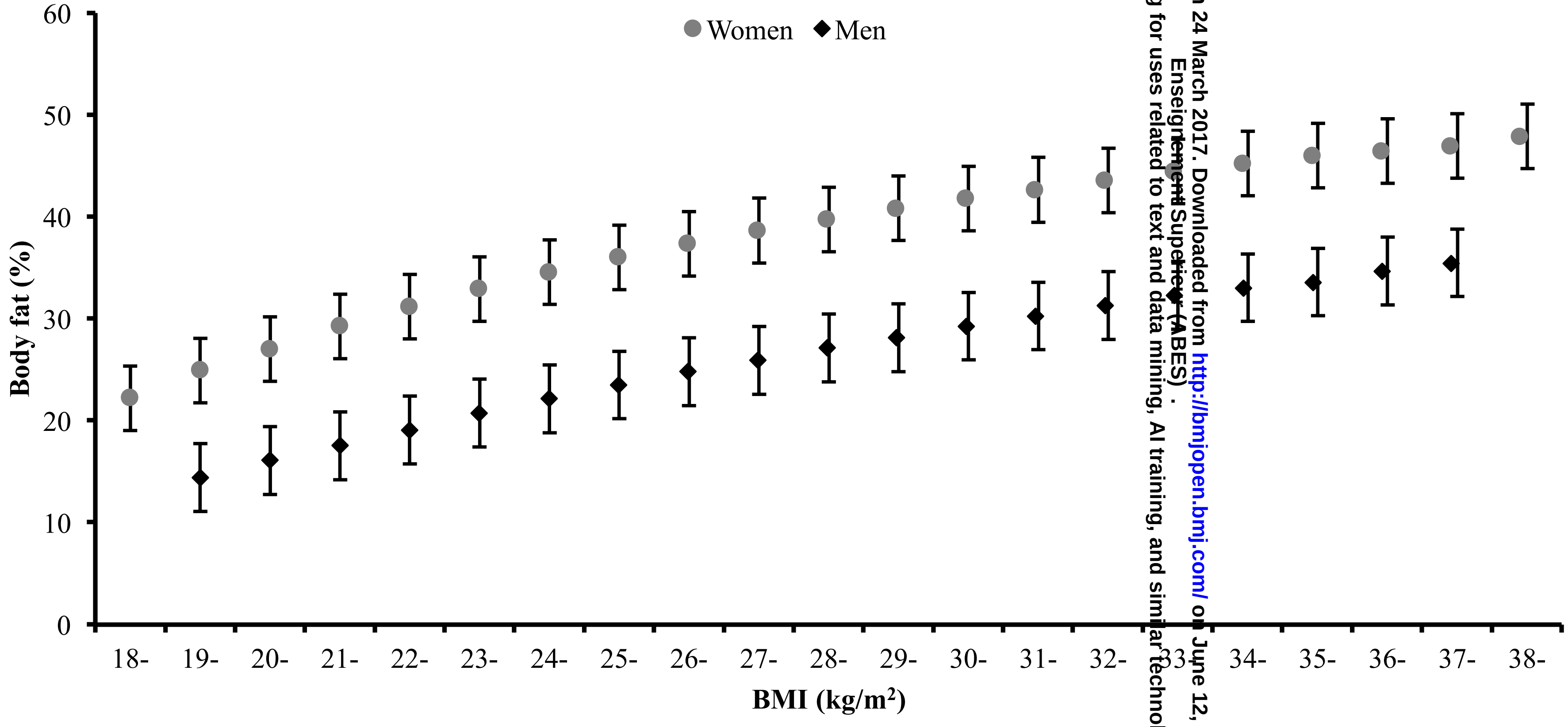

Figure S3 Body fat percentage by BMI for participants aged 60 years or older in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

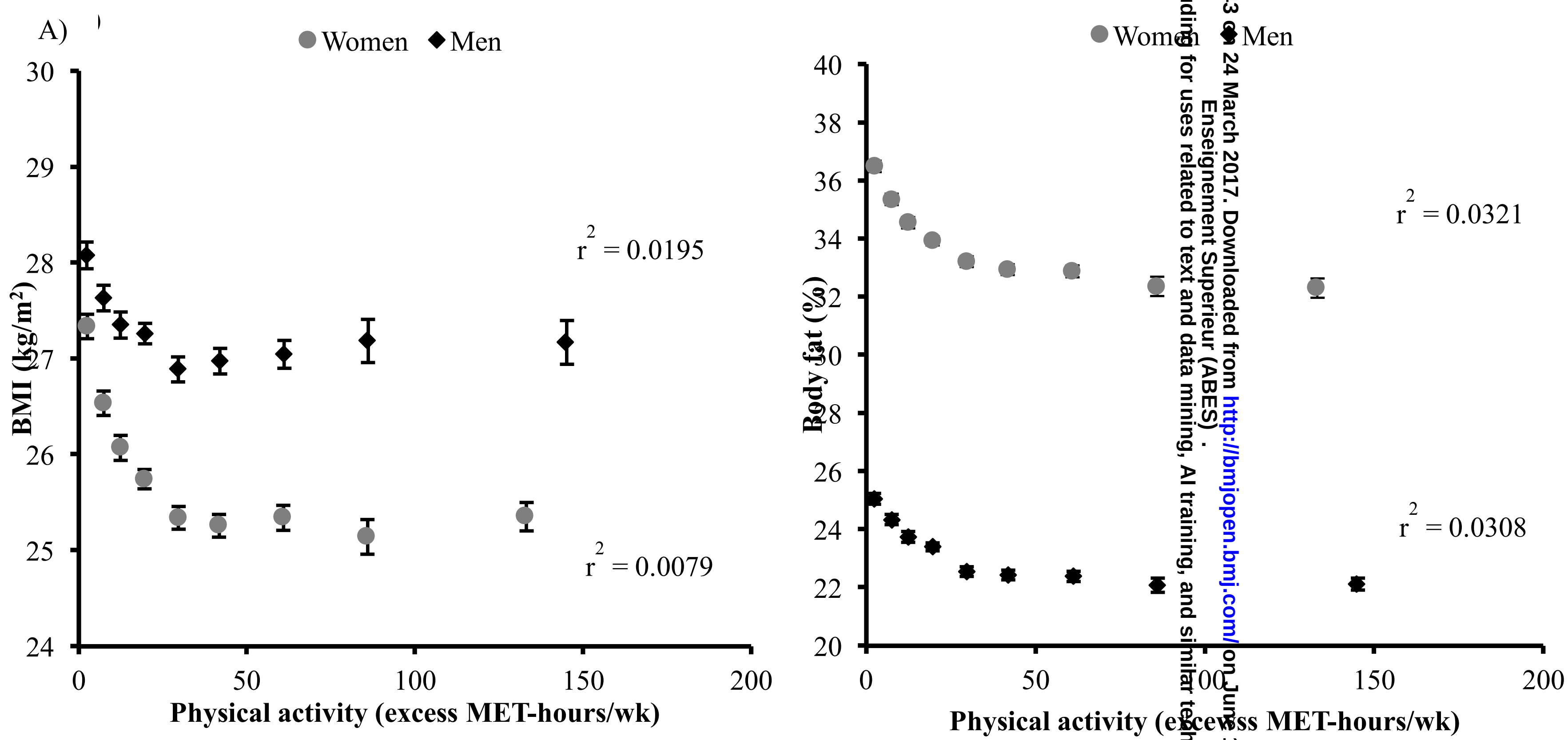

Figure S4 Mean BMI and body fat percentage by physical activity for participants aged younger than 50 years in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

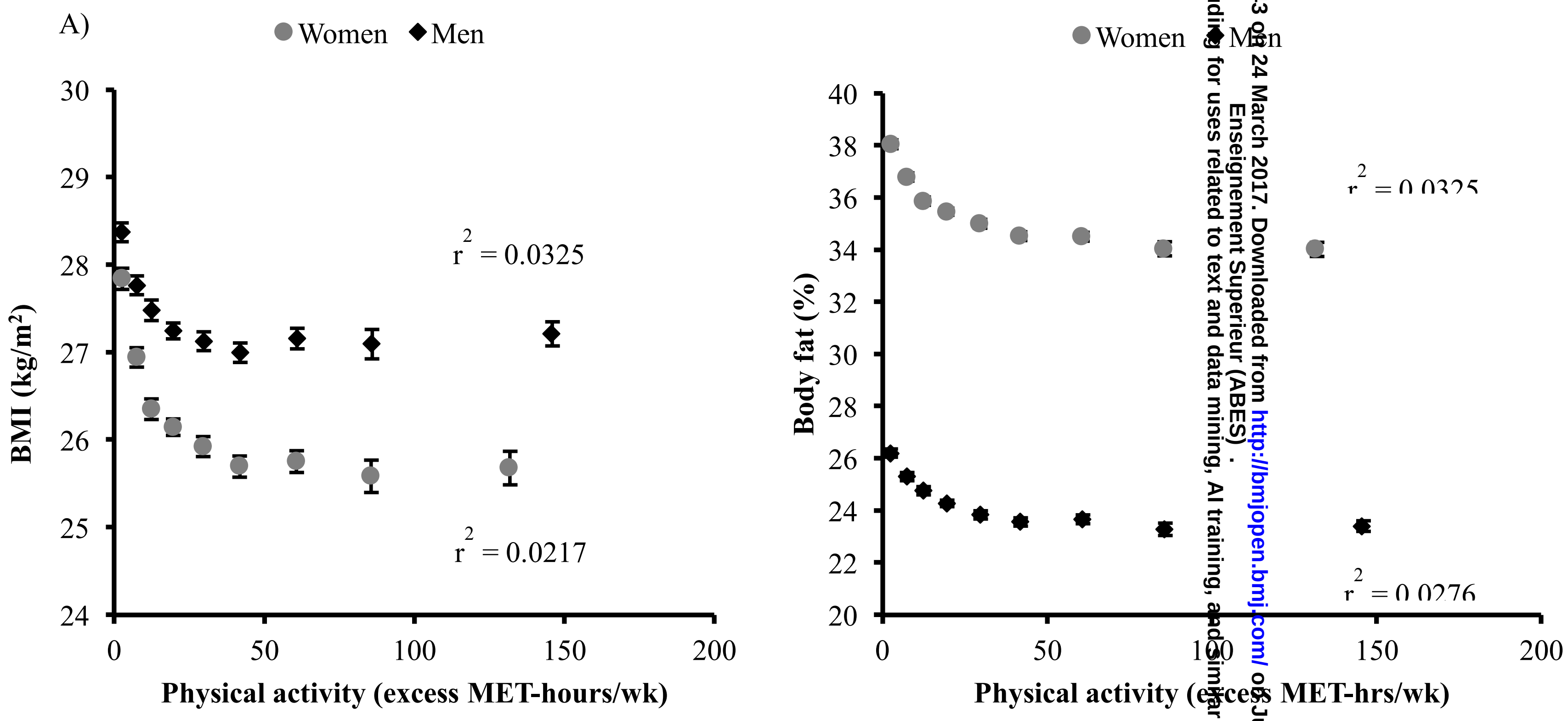

Figure S5 Mean BMI and body fat percentage by physical activity in participants aged 50-59 years in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

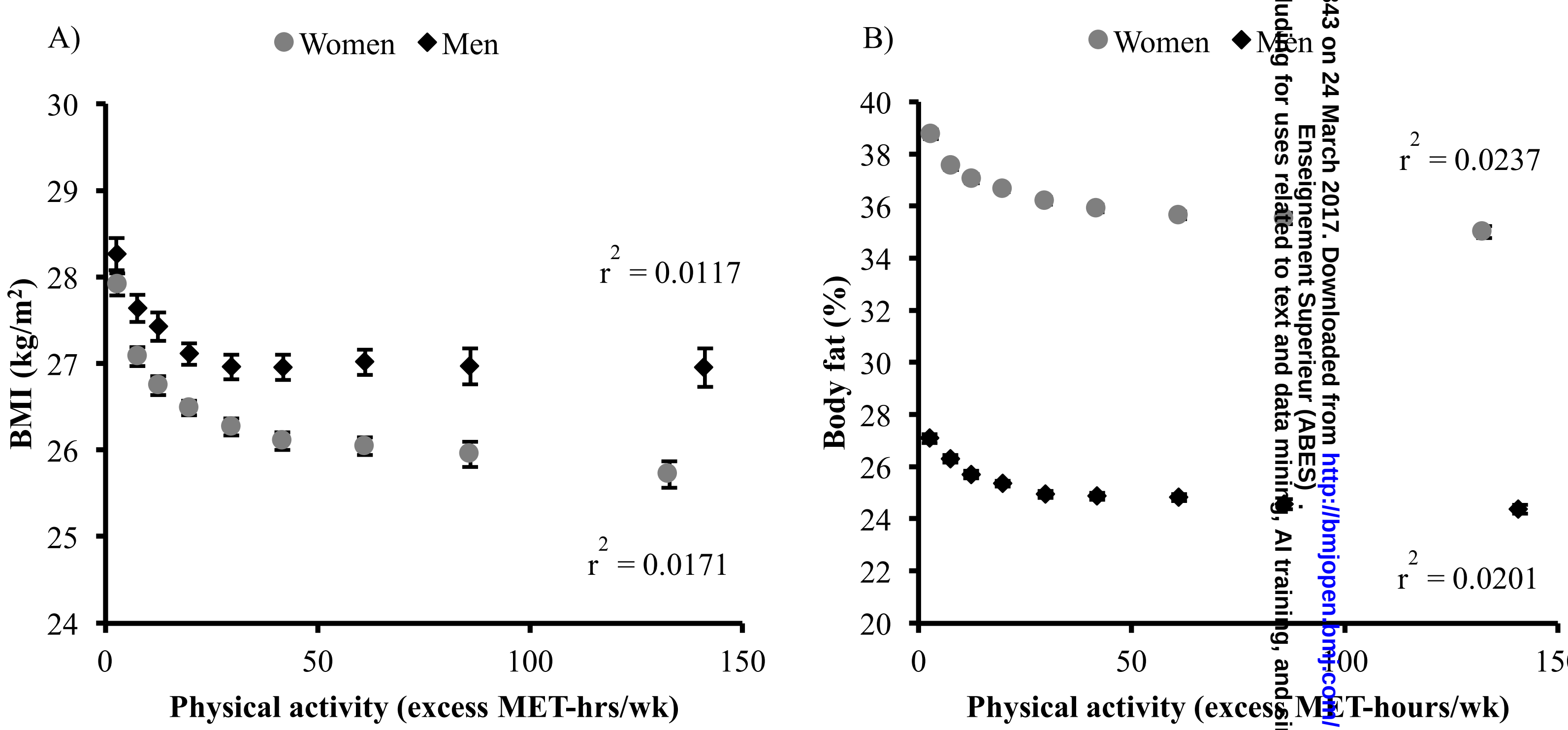

Figure S6 Mean BMI and body fat percentage by physical activity in participants aged 60 years or older in UK Biobank
Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)
Values are mean BMI and body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Errors bars are 95% CI
Estimates shown for cells with 200 or more participants

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract Title, and Pg 3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found Pg 3
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Pg 5
Objectives	3	State specific objectives, including any prespecified hypotheses Pg 5
Methods		
Study design	4	Present key elements of study design early in the paper Pg 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Pg 6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants Pg 8
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Pg 9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Pgs 6-8, and Footnotes for Table 1 and Table 2
Bias	9	Describe any efforts to address potential sources of bias Pg 10
Study size	10	Explain how the study size was arrived at Pg 8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Pg 9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding Pgs 9-10
		(*b*) Describe any methods used to examine subgroups and interactions Pgs 9-10
		(*c*) Explain how missing data were addressed Pg 8
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(*e*) Describe any sensitivity analyses Pg 9

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Pg 12, and Figure 1
		(b) Give reasons for non-participation at each stage Figure 1
		(c) Consider use of a flow diagram Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Pg 12, and Tables 1 and 2
		(b) Indicate number of participants with missing data for each variable of interest Footnotes for Tables 1 and 2
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures Tables 1 and 2.
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included Pgs 12-13
		(*b*) Report category boundaries when continuous variables were categorized Pgs 9-10
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Pgs 13-14
Discussion		
Key results	18	Summarise key results with reference to study objectives Pg 15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Pgs 15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence Pg 17
Generalisability	21	Discuss the generalisability (external validity) of the study results Pgs 16-17
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based Pg 18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

The association between physical activity and body fat percentage, with adjustment for BMI: a large cross-sectional analysis of UK Biobank

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-011843.R2
Article Type:	Research
Date Submitted by the Author:	08-Dec-2016
Complete List of Authors:	Bradbury, Kathryn; University of Oxford, Cancer Epidemiology Unit, Nuffield Department of Population Health Guo, Wenji; University of Oxford, Cancer Epidemiology Unit, Nuffield Department of Population Health Cairns, Benjamin; University of Oxford, Cancer Epidemiology Unit Armstrong, Miranda; University of Oxford, Cancer Epidemiology Unit, Nuffield Department of Population Health Key, Timothy; Oxford University, Cancer Research U.K. Epidemiology Unit, Unive
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Sports and exercise medicine, Research methods, Public health
Keywords:	Physical activity, UK Biobank, BMI, Body fat percentage

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The association between physical activity and body fat percentage, with adjustment for BMI: a large cross-sectional analysis of UK Biobank

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Abstract

Objectives: The objective of this study was to examine if, in the general population, physically active adults have less body fat after taking BMI into account.

Design: A cross-sectional analysis of participants recruited into UK Biobank in 2006-2010.

Setting: UK Biobank assessment centres throughout the UK.

Participants: 119,230 men and 140,578 women aged 40-69 years, with complete physical activity information, and without a self-reported long-term illness, disability or infirmity.

Exposures: Physical activity measured as excess MET-hours per week, estimated from a combination of walking, and moderate and vigorous physical activity. BMI from measured height and weight.

Main outcome measure: Body fat percentage estimated from bio-impedance.

Results: BMI and body fat percentage were highly correlated (r=0.85 in women; r=0.79 in men), and both were inversely associated with physical activity. Compared to <5 excess metabolic equivalent (MET)-hours per week at baseline, ≥100 excess MET-hours per week was associated with a 1.1 kg/m^2 lower BMI (27.1 versus 28.2 kg/m^2) and 2.8 percentage points lower body fat (23.4% versus 26.3%) in men, and 2.2 kg/m^2 lower BMI (25.6 versus 27.7 kg/m^2) and 4.0 percentage points lower body fat (33.9% versus 37.9%) in women. For a given BMI, greater physical activity was associated with lower average body fat percentage (for a BMI of 22.5-24.99 kg/m^2: 2.0 (95% CI: 1.8 to 2.2) percentage points lower body fat in men, and 1.8 (95% CI: 1.6 to 2.0) percentage points lower body fat in women, comparing ≥100 excess MET-hours per week to <5 excess MET-hours per week).

Conclusions: In this sample of middle-aged adults, drawn from the general population, physical activity was inversely associated with BMI and body fat percentage. For people with the same BMI, those who were more active had a lower body fat percentage.

Strengths and limitations of this study

- This study of middle-aged adults, drawn from the general population, is very large (n = 259,808) and height and weight (for the calculation of BMI) were measured by trained staff using standardised techniques.
- Body fat percentage (estimated via bio-impedance) was available for virtually all participants.
- Physical activity was self-reported and therefore there will be some measurement error associated with this variable.
- The study is cross-sectional and therefore we cannot infer cause and effect.

Introduction

Body mass index (BMI) is a simple index calculated from height and weight, and is usually used as a proxy for body fatness in large epidemiological studies. Correlations between BMI and more direct measures of body fatness are generally strong (r > 0.70) (1-4).

Observational studies have shown that people who do comparatively more physical activity have a lower BMI than less active people (5, 6). Few large epidemiological studies have directly estimated body fatness, and it is of interest to examine whether more comprehensive measures of body fatness provide additional information above and beyond that which is captured by BMI. Previous studies each of approximately 500 young adults have found that, for a given BMI, athletes have a lower body fat percentage than non-athletes (7, 8); however it is unclear whether in the general population of middle-aged adults, those who do more physical activity have a lower body fat percentage than those who do minimal physical activity, after taking into account BMI.

UK Biobank is a population-based cohort of 500,000 UK men and women, aged 40-69 years at recruitment. Body mass index and body fat percentage were measured at recruitment for virtually all participants. For this analysis of data from UK Biobank we aimed firstly to describe the associations of physical activity with BMI and body fat percentage, and secondly to determine whether physical activity is associated with body fat percentage, independently of BMI.

METHODS

Subjects

UK Biobank is a prospective cohort of approximately 500,000 people aged 40-69 years, recruited in 2006-2010 in the UK (9). People aged 40-69 years who lived within reasonable travelling distance of 22 assessment centres were identified from National Health Service patient registers and invited to participate in UK Biobank by attending an assessment centre. Permission for access to patient records for recruitment was approved by the National Information Governance Board for Health and Social Care in England and Wales, and the Community Health Index Advisory Group in Scotland. A sub-sample of approximately 20,000 participants completed a full repeat of the assessment centre visit between August 2012 and June 2013, approximately 5 years after recruitment (10). UK Biobank has ethical approval from the North West Multi-centre Research Ethics Committee. The UK Biobank protocol is available online (http://www.ukbiobank.ac.uk/wp-content/uploads/2011/11/UK-Biobank-Protocol.pdf). The touchscreen questionnaire and other resources are also available on the UK Biobank website (http://www.ukbiobank.ac.uk/resources/).

Anthropometric measurements

At the UK Biobank assessment centres, a touchscreen questionnaire was used to collect information on socio-demographic characteristics and lifestyle exposures. Socks and shoes were removed and height was measured using the Seca 202 height measure (Seca, Hamburg, Germany). Weight and estimated percentage fat were measured with the Tanita BC418ma bio-impedance device (Tanita, Tokyo, Japan). Participants were not asked to fast, nor were they given any specific instructions pertaining to the bio-impedance measures prior to attending the assessment centre. Water was available at all times throughout the visit and visits occurred throughout the day (8am-8pm).

Physical activity assessment

Questions on the touchscreen about walking, moderate physical activity, and vigorous physical activity, which were similar to those used in the short form of the International Physical Activity Questionnaire (11), were used to estimate excess metabolic equivalents (MET)-hours per week of physical activity during work and leisure time. For each of the three activity categories (walking, moderate physical activity, and vigorous physical activity) participants were asked how many days in a typical week they did each of the activities for 10 minutes or more (for walking: touchscreen question number WP1, UK Biobank variable n_864_0_0; for moderate physical activity: touchscreen question number WP2, UK Biobank variable n_884_0_0; for vigorous physical activity: touchscreen question number WP3, UK Biobank variable n_904_0_0). For each category, participants who entered one or more days were then asked how many minutes they spent doing those activities on a typical day (for walking: WP1A, n_874_0_0; for moderate physical activity: WP2A, n_894_0_0; for vigorous physical activity: WP3A, n_914_0_0). For each activity category, the number of reported days was multiplied by the number of reported minutes on a typical day to generate duration of activity in minutes per week.

Activity on a typical day of less than 10 minutes was recoded to 0 for any of the three categories of activity. For each of the three categories of activity, values of more than 1260 minutes per week (equivalent to an average of 3 hours per day) were truncated at 1260 (11).

Total MET values for each category from the International Physical Activity Questionnaire short form were: 3.3 for walking, 4.0 for moderate physical activity, and 8.0 for vigorous physical activity (11). We report excess METs, which are calculated by subtracting 1 MET from the value for each activity, and represent the energy expenditure above that of an inactive person (12). Excess MET values were therefore 2.3 for walking, 3.0 for moderate physical activity, and 7.0 for vigorous physical activity. Excess MET-hours per week were calculated by multiplying the excess MET value for each activity by the duration of activity in hours per week (11).

Exclusions

The UK Biobank dataset used for this analysis included 502,640 participants. Participants were excluded from this analysis if they selected 'Prefer not to answer' or 'Do not know' to any of the possible six questions on physical activity (WP1, WP1A, WP2, WP2A, WP3, WP3A) (n = 66,625). Participants were also excluded from this analysis if they responded to the question: "Do you have a long-term illness, disability or infirmity?" with 'Yes' (n = 159,941), 'Prefer not to answer' (n = 1,052) or 'Do not know' (n = 11,391), or if they had a missing value for this variable (n = 919) (touchscreen question number H4, UK Biobank variable n_2188_0_0). In addition, the questions used in the pilot study on the duration of physical activity differed from those in the main study, and participants who answered the pilot version of these questions were excluded (n = 2,253). Based on the International Physical Activity Questionnaire recommendations for data cleaning and processing (11), participants were also excluded from the analysis if the sum of walking, moderate physical activity, and vigorous physical activity was greater than 112 hours per week (n = 651), leaving a total of 259,808 participants in the present study.

Statistics

STATA version 14.0 (Stata Corp LP, College Station, TX) was used for all statistical analyses. All analyses were done for men and women separately. Participant characteristics were described by level of physical activity (low, < 10.0; moderate, 10.0-49.9; high, ≥ 50 excess MET-hours per week). Pearson's correlation coefficients between BMI and body fat percentage were calculated; values of 0.80 or above are considered very strong, values between 0.60-0.79 strong, 0.40-0.59 moderate, 0.20-0.39 weak, and 0.00-0.19 very weak (13). Multiple linear regression was used to calculate the mean body fat percentage in single units of BMI (e.g. 17.00-17.99, 18.00-18.99, 19.00-19.99 kg/m^2, etc), adjusted for age (5 year categories: < 45 years, 45-49.99 years, 50-54.99 years, 55-59.99 years, 60-64.99 years, ≥ 65.00 years). Groups with 200 or more participants are shown in the Figure. Multiple linear regression was also used to calculate mean BMI and body fat percentage in categories of excess MET-hours per week (< 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hours per week), adjusted for age (5 year categories, as above). For the final analysis, we used multiple linear regression to examine the association between physical activity (in excess MET-hours per week: < 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100) and body fat percentage (continuous variable). Body mass index (in 2.5 unit categories, e.g. < 18.50, 18.50-19.99, 20.00-22.49, 22.50-24.99, 25.00-27.49…,42.50-44.99, ≥ 45.00 kg/m^2, etc) and age (5 year categories) were included as covariates. We included a product term of excess MET-hours per week (categories, as above) and BMI (in 2.5 unit categories as above) in the model to calculate mean body fat percentage in categories of physical activity within strata of BMI. In additional sensitivity analyses, we adjusted for reported intakes of fruit and vegetables (< 3.00 servings/week, 3.00-3.99, 4.00-4.99, 5.00-5.99, ≥ 6.00 servings/week, unknown), and red and processed meat (< 2.00 servings/week, 2.00-2.99, 3.00-3.99, 4.00-4.99, ≥ 5.00 servings/week, unknown). We also restricted the analysis to those with a university or college degree, and separately, to those that do not have a job that usually or always involves standing or walking or manual work.

We also examined mean BMI and body fat percentage in 5 year age categories. For each age decade separately (i.e. participants < 50 years, 50-59 years, and ≥ 60 years) linear regression was used to calculate mean body fat percentage in single units of BMI, and to calculate mean BMI and body fat percentage in each category of physical activity (< 5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hours per week).

To explore the repeatability of self-reported physical activity, including effects of measurement error and possible changes in activity over time, we used a sub-sample of 10,225 UK Biobank participants who were eligible for the current study and who completed a repeat assessment visit approximately 5 years after recruitment (Supplementary Tables S1 and S2). For these participants, we calculated excess MET-hours per week from their answers to the touchscreen questionnaire completed at the repeat assessment centre visit, as described above. Then for each category of excess MET-hours per week defined at baseline, we calculated both the mean excess MET-hours per week at their baseline visit (to assess comparability of the sub-sample to the full cohort) and the mean excess MET-hours per week at the repeat visit (to assess measurement error in reporting physical activity and change over time). The sub-sample of participants who completed a repeat assessment centre visit approximately 5 years after recruitment was similar at baseline to the full cohort with regard to reported physical activity. However, at the repeat assessment, for participants in the highest category of physical activity defined at baseline (≥ 100 excess MET-hours per week), the mean excess MET-hours per week was much lower than at baseline (80 compared to 130 for both men and women). For the lowest category of physical activity defined at baseline, the mean excess MET-hours per week was somewhat higher at the repeat assessment than at baseline (12 compared to 2.6 for both men and women). Overall, this represents regression to the mean of almost 50% (calculated from the ratio of the range of mean values at the repeat assessment to the range of mean values at baseline). The Pearson's correlation coefficients between recruitment and repeat measurements of BMI and body fat percentage in the sub-sample of participants who completed a repeat assessment centre visit were 0.92 for both BMI and body fat percentage.

All *p* values were two-sided and $P < 0.05$ was considered statistically significant.

RESULTS

Participant flow is shown in Figure 1. Participants who had a high level of physical activity were older, had a lower BMI, a lower body fat percentage, and a higher intake of fruit and vegetables than participants with a low level of physical activity (Table 1 and Table 2). They were also less likely to have a college or university degree, and much more likely to have a standing or manual job than those with a moderate or low level of physical activity. Participants with a moderate activity level were the least likely to be current smokers.

Body fat percentage was positively related to BMI (Figure 2). The correlation between BMI and body fat percentage was very strong in women (r = 0.85), and strong in men (r = 0.79). At the same BMI, women had a much higher body fat percentage than men; for example, women with a BMI of 30.00-30.99 kg/m^2 had on average 41% body fat, whereas men with the same BMI had on average 28% body fat.

Body fat percentage and BMI were inversely related to physical activity (Figure 3). Men who did < 5 excess MET-hours of physical activity per week had, on average, a BMI of 28.2 kg/m^2 (95% Confidence Interval (CI): 28.2 to 28.3 kg/m^2) and 26.3% (95% CI: 26.2 to 26.4 kg/m^2) body fat. Men who did ≥100 excess MET-hours per week of physical activity per week had, on average, a BMI of 27.1 kg/m^2 (95% CI: 27.0 to 27.2 kg/m^2) and 23.4% (95% CI: 23.3 to 23.5%) body fat. Women who did < 5 excess MET-hours per week of physical activity per week had, on average, a BMI of 27.7 kg/m^2 (95% CI: 27.7 to 27.8 kg/m^2) and 37.9% (95% CI: 37.8 to 38.0%) body fat. Women who did ≥ 100 excess MET-hours per week of physical activity per week had, on average, a BMI of 25.6 kg/m^2 (95% CI: 25.5 to 25.7 kg/m^2) and a 33.9% (95% CI: 33.7 to 34.0%) body fat. For both men and women, as shown by the r^2 values, age and physical activity explained more of the variation in body fat

percentage than the variation in BMI in this study population; however, age and physical activity only explained a small proportion of the variation in both BMI and body fat percentage in this study population, with all r^2 values less than 0.06 (Figure 3).

Overall, in males, those doing ≥ 100 or more excess MET-hours per week compared with < 5 excess MET-hours per week had a 1.7 (95% CI: 1.6 to 1.7) percentage points lower body fat percentage, on average, after adjustment for BMI and age; in females it was on average 1.5 (95% CI: 1.4 to 1.6) percentage points lower. For both men and women, within each stratum of BMI, a higher physical activity level was associated with a lower body fat percentage, and the difference in body fat percentage between physical activity categories appeared to be slightly larger at lower BMIs (*p* for interaction using likelihood ratio test < 0.001, for both sexes) (Figure 4, Supplementary Tables S3 and S4). For a BMI of 22.5-24.99 kg/m^2, ≥ 100 excess MET-hours per week vs < 5 excess MET-hours per week was associated with 2.0 (95% CI: 1.8 to 2.2) percentage points lower body fat in men and 1.9 (95% CI: 1.6 to 2.0) percentage points lower body fat in women. For both men and women, within each stratum of BMI, the mean BMI was very similar across the categories of physical activity.

When we further adjusted for reported intakes of fruit and vegetables, and red and processed meats, or restricted the analysis to those who did not have an active job or those who had a university or college degree, the results were not materially altered. Comparing those doing ≥ 100 excess MET-hours per week to those doing < 5 excess MET-hours per week, body fat percentage was, on average 1.6 (95% CI: 1.5 to 1.7) percentage points lower for men and 1.4 (95% CI: 1.3 to 1.5) percentage points lower for women after adjustment for diet quality; 1.7 (95% CI: 1.6 to 1.9) percentage points lower for men and 1.6 (95% CI: 1.4 to 1.8) percentage points lower for women when restricting analyses to those who had a university or college

degree; and 1.6 (95% CI: 1.5 to 1.7) percentage points lower for men and 1.4 (95% CI: 1.3 to 1.5) percentage points lower for women when we restricted analyses to those who did not have a standing or manual job.

In men, the mean BMI was similar across 5-year age categories however the mean body fat percentage was higher in older age groups. In women, the mean BMI by 5-year age categories was slightly higher in older age groups, and the mean body fat percentage was also higher in older age groups (Supplementary Table S5). The association between BMI and body fat percentage was similar in each age decade (Supplementary Figures S1, S2, and S3). The differences in BMI between the extreme categories of physical activity were slightly larger and the differences in body fat percentage were slightly smaller with older age (Supplementary Figures S4, S5 and S6).

DISCUSSION

In this large sample of middle-aged British men and women, more physical activity was associated with both a lower BMI and a lower body fat percentage, although even men and women who did the most physical activity were, on average, overweight. More physical activity was also associated with a lower body fat percentage within each category of BMI, with an average 1-2 percentage points lower body fat in the most active, compared to the least active individuals. Most of the difference in body fat percentage with physical activity was between the very low and moderately-high levels of physical activity (<5 and 35-49.9 excess MET-hours per week, respectively); there was relatively little difference in body fat percentage between moderately-high and very high levels of physical activity (35-49.9 and ≥100 excess MET-hours per week, respectively).

The current study is large, and height and weight were measured by trained staff using standardised techniques. We examined whether important lifestyle factors (diet quality, education, and job type) which varied by physical activity level might modify the associations between physical activity, BMI and body fat percentage. In each of these sensitivity analyses, the results were essentially unchanged, although because this is an observational study we cannot rule out confounding by other factors. A limitation of the study is that physical activity was self-reported. Analysis of the sub-sample who had a repeat measurement of physical activity approximately 5 years after baseline indicates approximately 50% regression to the mean, which represents both the error in reporting physical activity and true changes in physical activity over time. The likely consequence of regression to the mean in physical activity levels over time is bias of associations towards the null, so that the true association between physical activity and body composition measures is likely to be stronger than that observed in this study. Participants were not given any specific instructions prior to body fat measurement. Hydration status, exercise and food consumption can have small effects on body fat values measured by bioimpedance; had these factors been standardised between participants, we may have seen slightly stronger associations between body fat percentage and physical activity. The study is cross-sectional, and therefore we can only show associations between reported physical activity and contemporaneous body composition. We cannot infer cause and effect: lower levels of physical activity may lead to greater adiposity, but it is also possible that increased adiposity leads to less physical activity.

Previous small studies (n<200), in young athletic populations have found inverse relationships between measures of physical fitness and BMI and body fat percentage (14, 15). Small studies (n~500) in young adults have also shown that, for a given BMI, athletes have a lower body fat percentage than non-athletes (7, 8). These findings are, however, of limited relevance to older adults in the general population, who experience the highest burden of obesity-related disease. An analysis of 466,605 participants in the China Kadoorie Biobank, aged 30-79 years, found relatively weak associations between physical activity and either BMI or body fat percentage: a difference of approximately 100 total MET-hours per week was associated with 0.15 kg/m^2 lower BMI, and 0.48 percentage points lower body fat (16). Participants in the China Kadoorie Biobank differed from those in UK Biobank in ethnicity and lifestyle, and also had a lower average BMI (23.4 (SD 3.2) kg/m^2 in men; 23.8 (SD 3.4) kg/m^2 in women). Their physical activity levels were comparable to the middle to upper range of physical activity of UK Biobank participants, and in this range we also saw only a small difference in body fat percentage.

Variation in BMI in the general population is largely due to differences in body fatness, but by definition it incorporates both adipose and lean body mass, and it is therefore difficult to disentangle the roles of adipose and lean mass in associations of BMI with health outcomes. For example, a higher BMI is an established risk factor for post-menopausal breast cancer, and probably increases risk through higher circulating sex hormones produced by the enzyme aromatase in the adipose tissue from precursor androgens (17). Several cohort studies have also shown that more physical activity is associated with a reduced risk of post-menopausal breast cancer, even after adjustment for BMI, and this finding is often taken as evidence that physical activity is independent of adiposity as a risk factor for post-menopausal breast cancer (18). Our results suggest, however, that adjustment for BMI may not have fully controlled for adiposity in these analyses.

In conclusion, in this sample of middle-aged British adults who were free from self-reported long-standing illness, men and women who reported doing the most physical activity had a lower BMI and a lower body fat percentage than those who reported doing the least physical activity. We also report new evidence that, for a given BMI, men and women who reported doing more physical activity had a lower body fat percentage; the greatest difference was observed between low and moderate levels of physical activity. BMI incorporates both adipose and lean mass, but is most strongly related to adiposity, and consequently is associated with morbidity and mortality from a wide range of diseases. However, to disentangle the possible effects of physical activity and adiposity on disease risk, future research should focus on more specific measures of adiposity.

Competing interests: All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

Contributorship: KEB and TJK conceived the research, KEB performed the statistical analyses; BJC contributed to the statistical methodology; MEGA contributed to generation of the physical activity variables. KEB, WG, BJC, MEGA, and TJK interpreted the data, drafted and reviewed the article for important intellectual content, KEB has primary responsibility for the final content. All authors read and approved the final manuscript. KEB is the guarantor for the study. This research has been conducted using the UK Biobank Resource under Application Number 3037.

Ethics approval: UK Biobank has ethical approval from the North West Multi-centre Research Ethics Committee. Participants gave informed consent on the touchscreen before taking part.

Funding: The authors are supported by Girdlers' New Zealand Health Research Council Fellowship (KEB), Cancer Research UK (TJK; C8221/A19170 and 570/A16491), the BHF Centre of Research Excellence, Oxford (BJC; BHF no. RE/13/1/30181), the UK Medical Research Council (MEGA, and TJK; MR/M012190/1), and the Clarendon Fund and US-UK Fulbright Commission (WG). The funders did not influence the conduct of the study, analysis or interpretation of the data, the writing of this report, or the decision to publish. The authors had full access to all the data in the study, can take responsibility for the integrity of the data, and the accuracy of the data analysis.

Data sharing: UK Biobank is an open access resource. Bona fide researchers can apply to use the UK Biobank dataset by registering and applying at http://www.ukbiobank.ac.uk/register-apply/. Statistical code for used for this manuscript is available to other researchers on request by emailing Kathryn Bradbury (kathryn.bradbury@ceu.ox.ac.uk).

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Table1 Characteristics of men participating in UK Biobank by physical activity

	Low activity < 10 excess MET-hours/wk[1] *n* = 26,405	Moderate activity 10-49.9 excess MET-hours/wk[1] *n* = 63,022	High activity ≥ 50 excess MET-hours/wk[1] *n* = 29,803	All men *n* = 119,230
Age (years)				
Mean (SD)	55.3 (8.0)	55.7 (8.4)	56.0 (8.4)	55.7 (8.3)
White ethnicity[a]	24,741 (93.7)	59,842 (95.0)	28,468 (95.5)	113,051 (94.8)
Socioeconomic status[b]				
Upper fifth	6,274 (23.8)	14,701 (23.4)	5,867 (19.7)	26,842 (22.5)
Qualifications[c]				
College or University degree/vocational qualification	18,878 (71.5)	45,453 (72.2)	17,731 (59.5)	82,062 (68.8)
BMI (kg/m^2)[d]				
Mean (SD)	28.0 (4.2)	27.1 (3.7)	27.1 (3.6)	27.3 (3.8)
< 20.00	238 (0.9)	559 (0.9)	289 (1.0)	1,086 (0.9)
20.00-24.99	5,849 (22.2)	17,425 (27.7)	8,326 (28.0)	31,600 (26.6)

25.00-29.99	13,220 (50.2)	32,745 (52.1)	15,403 (51.8)	61,368 (51.6)
≥ 30.00-34.99	7,015 (26.7)	12,135 (19.3)	5,699 (19.2)	24,849 (20.9)
Body fat (%)[e]				
Mean (SD)	25.8 (5.5)	24.2 (5.4)	23.6 (5.5)	24.4 (5.5)
< 15.00	761 (2.9)	3,062 (4.9)	1,945 (6.6)	5,768 (4.9)
15.00-19.99	2,810 (10.8)	9,714 (15.6)	5,148 (17.5)	17,672 (15.0)
20.00-24.99	7,714 (29.6)	21,023 (33.7)	10,080 (34.3)	38,817 (32.9)
25.00-29.99	9,194 (35.2)	19,816 (31.8)	8,686 (29.5)	37,696 (32.0)
≥ 30.00	5,629 (21.6)	8,703 (14.0)	3,558 (12.1)	17,890 (15.2)
Height (m)[f]				
< 1.70	3,902 (14.8)	9,251 (14.7)	5,467 (18.4)	18,620 (15.7)
1.70 - 1.74	6,250 (23.8)	15,301 (24.4)	7,917 (26.6)	29,468 (24.8)
1.75 - 1.79	7,738 (29.4)	18,182 (28.9)	8,246 (27.8)	34,166 (28.7)
1.80 - 1.84	5,308 (20.2)	12,992 (20.7)	5,408 (18.2)	23,708 (19.9)
≥ 1.85	3,115 (11.8)	7,120 (11.3)	2,682 (9.0)	12,917 (10.9)
Mean (SD) excess MET-hours per week[g]	5.1 (2.9)	25.8 (11.0)	92.9 (43.3)	38.0 (40.1)
Standing or walking job[h]	2,524 (12.7)	9,766 (23.1)	12,961 (65.4)	25,251 (30.8)

Manual job[i]	561 (2.8)	3,214 (7.6)	8,145 (41.1)	11,920 (14.6)
Smoking status[1j]				
Never	14,269 (54.0)	34,209 (54.3)	15,101 (50.7)	63,579 (53.3)
Previous	8,866 (33.6)	22,438 (35.6)	10,936 (36.7)	42,240 (35.4)
Current	3,215 (12.2)	6,252 (9.9)	3,680 (12.4)	13,147 (11.0)
Alcohol consumption[k]				
Three or more times a week	14,391 (54.5)	36,542 (58.0)	15,477 (52.0)	66,410 (55.8)
Fruit and vegetable consumption[l]				
< 3.00 servings per day	8,754 (33.2)	14,052 (22.3)	5,966 (20.0)	28,772 (24.1)
3.00-3.99 servings per day	6,031 (22.8)	13,370 (21.2)	5,204 (17.5)	24,605 (20.6)
4.00-4.99 servings per day	4,619 (17.5)	12,622 (20.0)	5,485 (18.4)	22,726 (19.1)
5.00-5.99 servings per day	2,926 (11.1)	8,930 (14.2)	4,389 (14.7)	16,245 (13.6)
≥ 6.00 servings per day	3,798 (14.4)	13,559 (21.5)	8,405 (28.2)	25,762 (21.6)
Total red and processed meat consumption[m]				
< 2.00 times per week	2,120 (8.0)	5,838 (9.3)	2,956 (9.9)	10,914 (9.2)
2.00-2.99 times a week	6,291 (23.8)	16,042 (25.5)	7,170 (24.1)	29,503 (24.7)
3.00-3.99 times a week	3,927 (14.9)	9,323 (14.8)	4,186 (14.1)	17,436 (14.6)

4.00-4.99 times a week	4,866 (18.4)	10,990 (17.4)	5,069 (17.0)	20,925 (17.6)
≥ 5.00 times a week	9,042 (34.2)	20,523 (32.6)	10,229 (34.3)	39,794 (33.4)

Values are number (%) unless otherwise stated

Number of participants with missing data (the total number participants who have missing data, or who reported ‘do not know’ or ‘prefer not to answer’) for each characteristic is as follows: 0 for age, 377 for ethnicity, 159 for socioeconomic status, 705 for qualifications, 327 for BMI, 1,367 for body fat %, 351 for height, 0 for excess MET-hours/wk, 57 for standing or walking job, 38 for manual job, 264 for smoking status, 35 for alcohol consumption, 1,120 for fruit and vegetable consumption, 658 for total red and processed meat consumption

[a]Participants who reported their ethnicity as ‘White’, ‘British’, ‘Irish’, or ‘Any other white background’

[b]We generated quintiles of socioeconmic status based on the Townsend deprivation index for the whole cohort (UK Biobank variable n_189_0_0)

[c]Vocational qualifications defined as other professional qualification (eg: nursing or teaching)/ National Vocational Qualification or Higher National Diploma or Higher National Certificate) (touchscreen question number D12, UK Biobank variable n_6138_0_0)

[d]We preferentially used BMI derived from height and weight measured during the impedance measurement (UK Biobank variable n_23104_0_0_), but if missing used the body size measures (UK Biobank variable n_21001_0_0); both of these are direct measures of height and weight made on the same day at the assessment centre

[e]Body fat % (UK Biobank variable n_23099_0_0)

[f]Standing height (UK Biobank variable n_50_0_0)

[g]Excess MET-hours/wk estimated from the combination of reported walking, moderate and vigorous physical activity (for details see methods text)

[h]Participants who reported their work 'usually' or 'always' involved walking or standing for most of the time (touchscreen question number D9B, UK Biobank variable n_806_0_0)

[i]Participants who reported their work 'usually' or 'always' involved heavy manual or physical work for most of the time (touchscreen question number D9C, UK Biobank variable n_816_0_0)

[j]Smoking status (UK Biobank variable n_20116_0_0)

[k]Participants who reported consuming alcohol three to four times per week or daily or almost daily (touchscreen question number A1, UK Biobank variable n_1558_0_0)

[l]Total fruit and vegetable consumption is the sum of fresh fruit intake (touchscreen question number DT3, UK Biobank variable n_1309_0_0), cooked vegetable intake (touchscreen question numbers DT1, UK Biobank variable n_1289_0_0) and raw vegetable intake (touchscreen question number DT1, and UK Biobank variable n_1299_0_0). To sum the frequencies, ‘Less than one’ was coded as 0.5, and we coded 1 piece of fresh fruit as a serving and 2 tablespoons of vegetables as a serving.

[m]Total red and processed meat consumption is the sum of processed meat (touchscreen question number DT8 and UK Biobank variable n_1349_0_0), beef (touchscreen question number DT7 and UK Biobank variable n_1369_0_0), lamb/mutton (touchscreen question number DT7A and UK Biobank variable n_1379_0_0) , and pork (touchscreen question number DT7B and UK Biobank variable n_1389) intake. To sum the frequencies, we used the following coding: ‘Never’ = 0, ‘Less than once a week’ = 0.5, ‘Once a week’ = 1, ‘2-4 times a week’ = 3, ‘5-6 times a week’ = 5.5, ‘Once or more daily’ = 7.

Table 2 Characteristics of women participating in UK Biobank by physical activity

	Low activity < 10 excess MET-hours/wk[1] *n* = 31,931	Moderate activity 10-49.9 excess MET-hours/wk[1] *n* = 78,171	High activity ≥ 50 excess MET-hours/wk[1] *n* = 30,476	All women *n* = 140,578
Age (years)				
Mean (SD)	54.6 (7.8)	55.2 (8.1)	56.2 (8.1)	55.3 (8.1)
White ethnicity[a]	30,164 (94.5)	74,471 (95.3)	29,088 (95.5)	133,723 (95.1)
Socioeconomic status[b]				
Upper fifth	6,956 (21.8)	17,177 (22.0)	6,407 (21.0)	30,540 (21.8)
Qualifications[c]				
College or University degree/vocational qualification	19,320 (60.5)	49,219 (62.9)	17,826 (58.5)	86,365 (61.5)
BMI (kg/m^2)[d]				
Mean (SD)	27.2 (5.1)	26.0 (4.4)	25.7 (4.2)	26.2 (4.6)
< 20.00	954 (3.0)	2,838 (3.6)	1,270 (4.2)	5,062 (3.6)

20.00-24.99	10,930 (34.3)	33,256 (42.7)	13,749 (45.2)	57,935 (41.3)
25.00-29.99	12,037 (37.8)	29,041 (37.2)	11,062 (36.4)	52,140 (37.2)
≥ 30.00-34.99	7,930 (24.9)	12,839 (16.5)	4,334 (14.3)	25,103 (17.9)
Body fat (%)[e]				
Mean (SD)	37.1 (6.6)	35.2 (6.5)	34.4 (6.6)	35.5 (6.7)
< 25.00	1,197 (3.8)	4,842 (6.3)	2,524 (8.4)	8,563 (6.2)
25.00-29.99	3,256 (10.3)	11,220 (14.5)	4,920 (16.3)	19,396 (14.0)
30.00-34.99	7,011 (22.2)	20,467 (26.5)	8,224 (27.3)	35.702 (25.7)
35.00-39.99	9,129 (29.0)	22,181 (28.7)	8,347 (27.7)	39,657 (28.6)
≥ 40.00	10,940 (34.7)	18,506 (24.0)	6,110 (20.3)	35,556 (25.6)
Height (m)[f]				
< 1.55	2,758 (8.7)	6,315 (8.1)	2,810 (9.2)	11,883 (8.5)
1.55 - 1.59	6,268 (19.7)	15,551 (19.9)	6,504 (21.4)	28,323 (20.2)
1.60 - 1.64	10,067 (31.6)	24,437 (31.3)	9,631 (31.7)	44,135 (31.5)
1.65 - 1.69	7,993 (25.1)	20,091 (25.8)	7,530 (24.8)	35,614 (25.4)
≥ 1.70	4,779 (15.0)	11,621 (14.9)	3,952 (13.0)	20,352 (14.5)
Mean (SD) excess MET-hours per week[g]	5.3 (2.8)	25.5 (10.9)	83.0 (33.3)	33.4 (32.5)

Standing or walking job[h]	3,901 (17.4)	12,349 (25.7)	9,593 (56.3)	25,843 (29.53)
Manual job[i]	521 (2.3)	2,576 (5.4)	3,883 (22.8)	6,980 (8.0)
Smoking status[j]				
Never	19,513 (61.1)	47,974 (61.4)	18,370 (60.3)	85,857 (61.1)
Previous	9,468 (29.7)	24,366 (31.2)	9,635 (31.6)	43,469 (30.9)
Current	2,883 (9.0)	5,661 (7.2)	2,417 (7.9)	10,961 (7.8)
Alcohol consumption[k]				
Three or more times a week	12,670 (39.7)	33,747 (43.2)	12,137 (39.8)	58,554 (41.7)
Fruit and vegetable consumption[l]				
< 3.00 servings per day	6,601 (20.7)	9,849 (12.6)	3,070 (10.1)	19,520 (13.9)
3.00-3.99 servings per day	6,507 (20.4)	13,485 (17.3)	4,232 (13.9)	24,224 (17.2)
4.00-4.99 servings per day	6,672 (20.9)	16,489 (21.1)	5,701 (18.7)	28,862 (20.5)
5.00-5.99 servings per day	5,092 (16.0)	14,460 (18.5)	5,573 (18.3)	25,125 (17.9)
≥ 6.00 servings per day	6,874 (21.5)	23,557 (30.1)	11,740 (38.5)	42,171 (30.0)
Total red and processed meat consumption[m]				
< 2.00 times per week	5,462 (17.1)	15,254 (19.5)	6,729 (22.1)	27,445 (19.5)
2.00-2.99 times a week	10,903 (34.2)	27,329 (35.0)	10,190 (33.4)	48,422 (34.4)

3.00-3.99 times a week	5,395 (16.9)	12,642 (16.2)	4,823 (15.8)	22,860 (16.3)
4.00-4.99 times a week	4,058 (12.7)	9,143 (11.7)	3,423 (11.2)	16,624 (11.8)
≥ 5.00 times a week	5,973 (18.7)	13,456 (17.2)	5,144 (16.9)	24,573 (17.5)

Values are number (%) unless otherwise stated

Number of participants with missing data (the total number participants who have missing data, or who reported ‘do not know’ or ‘prefer not to answer’) for each characteristic is as follows: 0 for age, 263 for ethnicity, 150 for socioeconomic status, 756 for qualifications, 338 for BMI, 1,704 for body fat %, 271 for height, 0 for excess MET-hours/wk, 64 for standing or walking job, 52 for manual job, 291 for smoking status, 44 for alcohol consumption, 676 for fruit and vegetable consumption, 655 for total red and processed meat consumption

[a]Participants who reported their ethnicity as ‘White’, ‘British’, ‘Irish’, or ‘Any other white background’

[b]We generated quintiles of socioeconmic status based on the Townsend deprivation index for the whole cohort (UK Biobank variable n_189_0_0)

[c]Vocational qualifications defined as other professional qualification (eg: nursing or teaching)/ National Vocational Qualification or Higher National Diploma or Higher National Certificate) (touchscreen question number D12, UK Biobank variable n_6138_0_0)

[d]We preferentially used BMI derived from height and weight measured during the impedance measurement (UK Biobank variable n_23104_0_0_), but if missing used the body size measures (UK Biobank variable n_21001_0_0); both of these are direct measures of height and weight made on the same day at the assessment centre.

[e]Body fat % (UK Biobank variable n_23099_0_0)

[f]Standing height (UK Biobank variable n_50_0_0)

[g]Excess MET-hours/wk estimated from the combination of reported walking, moderate and vigorous physical activity (for details see methods text)

[h]Participants who reported their work 'usually' or 'always' involved walking or standing for most of the time (touchscreen question number D9B, UK Biobank variable n_806_0_0)

[i]Participants who reported their work 'usually' or 'always' involved heavy manual or physical work for most of the time (touchscreen question number D9C, UK Biobank variable n_816_0_0)

[j]Smoking status (UK Biobank variable n_20116_0_0)

[k]Participants who reported consuming alcohol three to four times per week or daily or almost daily (touchscreen question number A1, UK Biobank variable n_1558_0_0)

[l]Total fruit and vegetable consumption is the sum of fresh fruit intake (touchscreen question number DT3, UK Biobank variable n_1309_0_0), cooked vegetable intake (touchscreen question numbers DT1, UK Biobank variable n_1289_0_0) and raw vegetable intake (touchscreen question number DT1, and UK Biobank variable n_1299_0_0). To sum the frequencies, ‘Less than one’ was coded as 0.5, and we coded 1 piece of fresh fruit as a serving and 2 tablespoons of vegetables as a serving.

[m]Total red and processed meat consumption is the sum of processed meat (touchscreen question number DT8 and UK Biobank variable n_1349_0_0), beef (touchscreen question number DT7 and UK Biobank variable n_1369_0_0), lamb/mutton (touchscreen question number DT7A and UK Biobank variable n_1379_0_0) , and pork (touchscreen question number DT7B and UK Biobank variable n_1389) intake. To sum the frequencies, we used the following coding: ‘Never’ = 0, ‘Less than once a week’ = 0.5, ‘Once a week’ = 1, ‘2-4 times a week’ = 3, ‘5-6 times a week’ = 5.5, ‘Once or more daily’ = 7.

Figure legends

Figure 1 UK Biobank participant flow diagram

MPA: moderate physical activity; VPA: vigorous physical activity

Figure 2 Body fat percentage by BMI in UK Biobank

Values are mean body fat % by single-unit BMI categories

Adjusted for age (5 year categories)

Error bars represent 1 SD either side of the mean

Estimates shown for cells with 200 or more participants

Figure 3 Mean BMI and body fat percentage by physical activity in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat % by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Adjusted for age (5 year categories)

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

Figure 4 Mean body fat percentage by physical activity, stratified by BMI category in UK Biobank

Panel A: men; Panel B: women

Values are mean body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Estimates shown for cells with 200 or more participants

Adjusted for age (5 year categories)

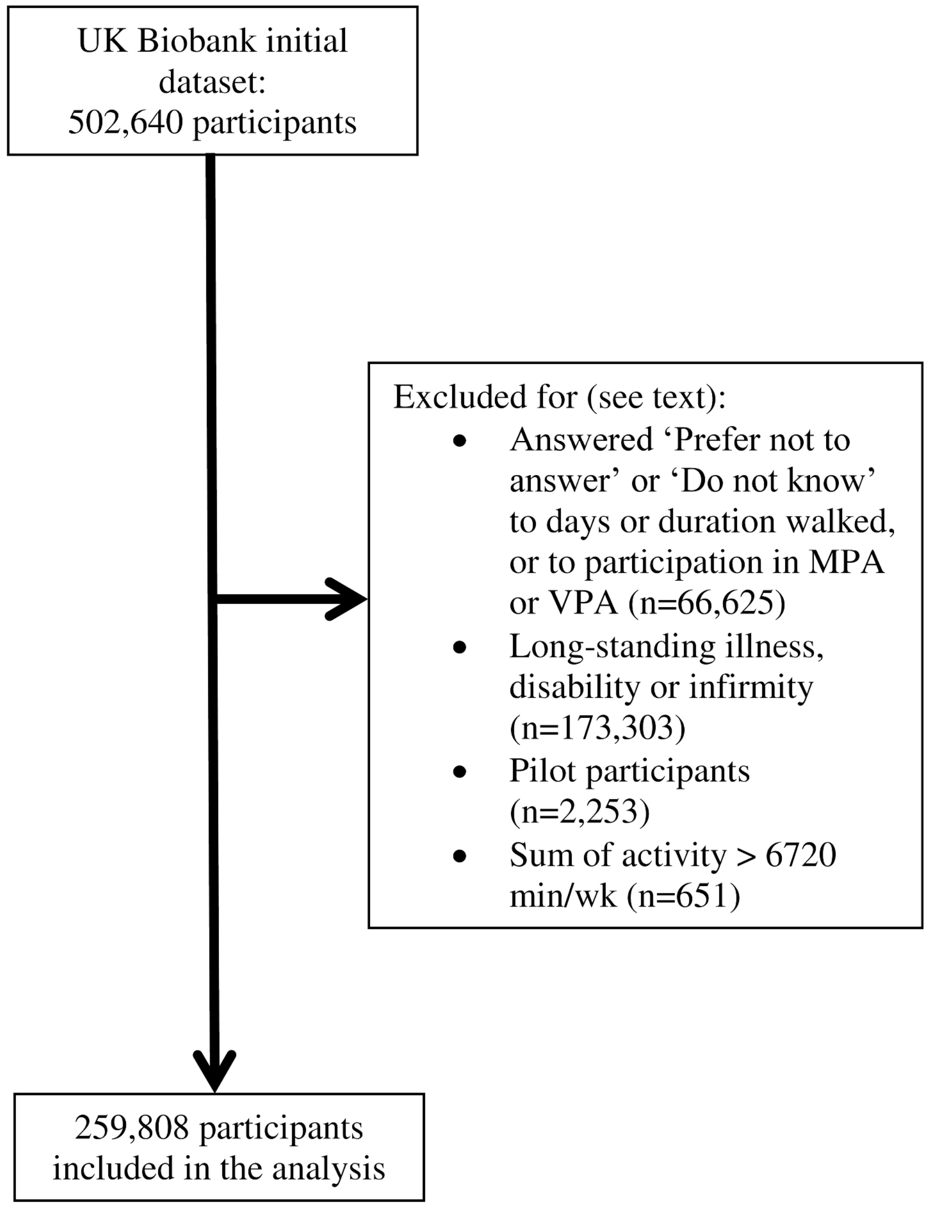

Figure 1 UK Biobank participant flow diagram
MPA: moderate physical activity; VPA: vigorous physical activity

262x342mm (300 x 300 DPI)

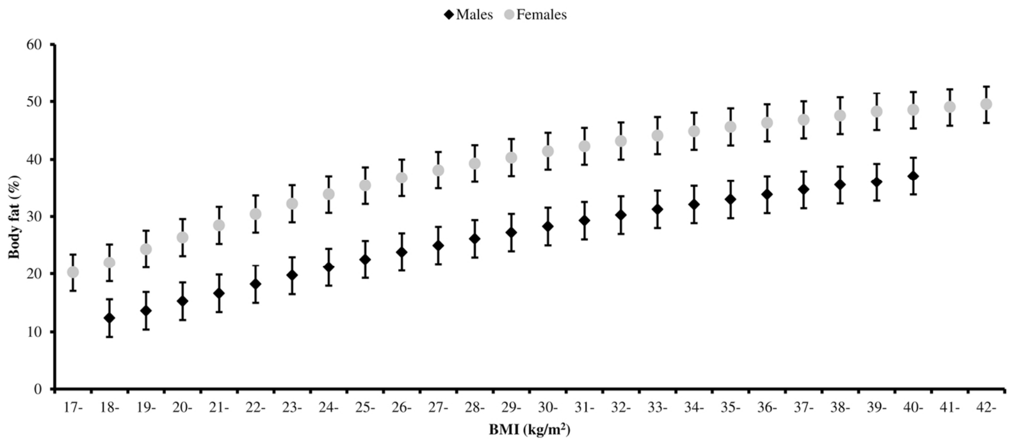

Figure 2 Body fat percentage by BMI in UK Biobank
Values are mean body fat % by single-unit BMI categories
Adjusted for age (5 year categories)
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

135x58mm (300 x 300 DPI)

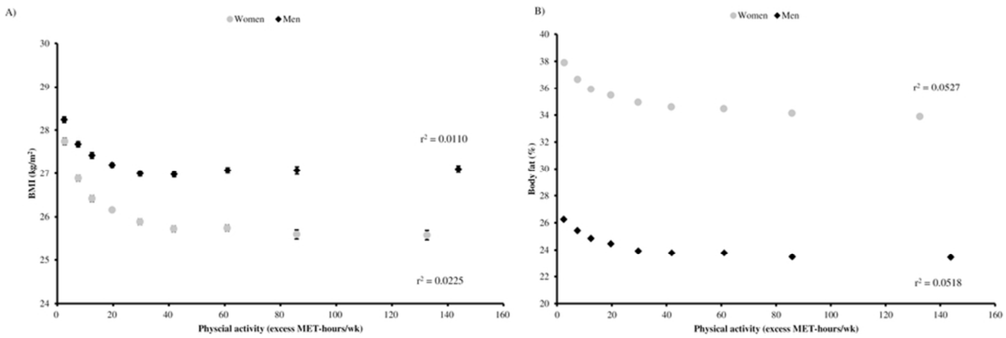

Figure 3 Mean BMI and body fat percentage by physical activity in UK Biobank
Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat % by physical activity (excess MET-hrs/wk)
Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Adjusted for age (5 year categories)
Errors bars are 95% CI
Estimates shown for cells with 200 or more participants

81x26mm (300 x 300 DPI)

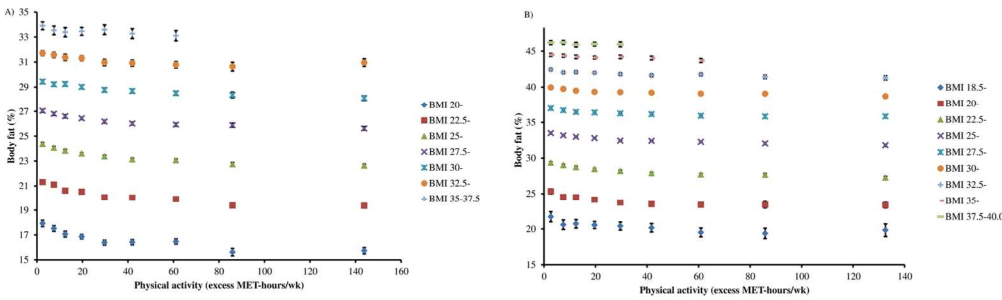

Figure 4 Mean body fat percentage by physical activity, stratified by BMI category in UK Biobank
Panel A: men; Panel B: women
Values are mean body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Estimates shown for cells with 200 or more participants
Adjusted for age (5 year categories)

141x40mm (300 x 300 DPI)

Table S1 Repeated measures of physical activity in men who completed the repeat assessment visit in UK Biobank 5 years after recruitment

	Physical activity (excess MET-hours per week)[a]								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥100
	All men (n = 119,230)								
Number of men	*12,613*	*13,792*	*12,381*	*20,983*	*15,023*	*14,635*	*13,415*	*7,043*	*9,345*
Baseline[b]	2.5	7.5	12.4	19.7	29.7	41.9	61.1	85.9	141.8
	Men who completed the repeat assessment visit (n = 5,158)								
Number of men	*602*	*614*	*534*	*943*	*691*	*631*	*541*	*279*	*323*
Baseline[b]	2.6	7.6	12.4	19.7	29.8	42.1	60.5	85.6	133.3
Repeat[b]	12.2	16.3	20.8	26.1	32.2	40.3	47.9	60.5	80.8

[a]Categories are defined from baseline data

[b]Values are mean excess MET-hours per week

Table S2 Repeated measures of physical activity in women who completed the repeat assessment visit in UK Biobank 5 years after recruitment

	Physical activity (excess MET-hours per week)[a]								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥100
	All women (n = 140,578)								
Number of women	*14,299*	*17,632*	*15,970*	*26,156*	*18,555*	*17,490*	*16,231*	*7,407*	*6,838*
Baseline[b]	2.6	7.5	12.4	19.6	29.6	41.7	60.9	85.8	[illegible]
	Women who completed the repeat assessment visit (n = 5,067)								
Number of women	*515*	*659*	*606*	*1,004*	*681*	*640*	*555*	*229*	*178*
Baseline[b]	2.6	7.6	12.3	19.6	29.7	41.7	61.0	85.0	[illegible]
Repeat[b]	11.9	18.5	21.3	26.1	33.2	40.6	52.8	59.2	[illegible]

[a]Categories are defined from baseline data

[b]Values are mean excess MET-hours per week

Table S3 Mean (95% CI) body fat percentage by categories of BMI and physical activity in men in UK Biobank.

Categories of BMI	Categories of physical activity (MET-hours/wk)								
	<5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
20-	16.6 (16.3-16.8) *n = 649*	16.1 (15.9-16.4) *n = 780*	15.7 (15.4-15.9) *n = 743*	15.4 (15.3-15.6) *n = 1356*	14.9 (14.7-15.1) *n = 1014*	15.0 (14.7-15.2) *n = 986*	15.0 (14.8-15.2) *n = 940*	14.1 (13.8-14.4) *n = 478*	14.3 (14.0-14.6) *n = 658*
Mean BMI	*21.6*	*21.5*	*21.5*	*21.5*	*21.5*	*21.5*	*21.6*	*21.5*	*21.5*
22.5-	19.9 (19.8-20.1) *n = 1943*	19.7 (19.6-19.8) *n = 2477*	19.2 (19.0-19.3) *n = 2411*	19.1 (19.0-19.2) *n = 4289*	18.6 (18.5-18.7) *n = 3379*	18.6 (18.4-18.7) *n = 3247*	18.4 (18.3-18.6) *n = 2851*	17.9 (17.7-18.1) *n = 1490*	17.9 (17.8-18.1) *n = 1909*
Mean BMI	*23.9*	*23.9*	*23.9*	*23.9*	*23.9*	*23.9*	*23.8*	*23.9*	*23.8*
25-	23.0 (22.9-23.1) *n = 3217*	22.7 (22.6-22.8) *n = 3861*	22.4 (22.3-22.5) *n = 3606*	22.2 (22.1-22.3) *n = 6180*	21.9 (21.8-22.0) *n = 4428*	21.7 (21.6-21.8) *n = 4419*	21.6 (21.5-21.7) *n = 3960*	21.3 (21.1-21.4) *n = 2095*	21.2 (21.1-21.3) *n = 2694*
Mean BMI	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*	*26.2*
27.5-	25.7 (25.6-25.8) *n = 2950*	25.4 (25.3-25.5) *n = 3192*	25.2 (25.1-25.3) *n = 2793*	25.0 (24.9-25.1) *n = 4818*	24.7 (24.6-24.9) *n = 3302*	24.6 (24.4-24.7) *n = 3199*	24.5 (24.3-24.6) *n = 2948*	24.4 (24.2-24.6) *n = 1561*	24.2 (24.0-24.3) *n = 2145*
Mean BMI	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*
30-	28.1 (27.9-28.2) *n = 1867*	27.8 (27.7-28.0) *n = 1780*	27.8 (27.7-28.0) *n = 1498*	27.6 (27.4-27.7) *n = 2409*	27.3 (27.2-27.5) *n = 1644*	27.2 (27.1-27.4) *n = 1585*	27.1 (26.9-27.2) *n = 1560*	26.9 (26.7-27.1) *n = 809*	26.7 (26.5-26.9) *n = 1107*
Mean BMI	*31.1*	*31.1*	*31.1*	*31.0*	*31.0*	*31.0*	*31.0*	*31.0*	*31.0*
32.5-	30.4 (30.2-30.6) *n = 984*	30.2 (30.0-30.4) *n = 873*	30.0 (29.7-30.2) *n = 663*	29.9 (29.7-30.1) *n = 1009*	29.5 (29.3-29.8) *n = 654*	29.5 (29.2-29.7) *n = 634*	29.3 (29.1-29.6) *n = 614*	29.2 (28.8-29.6) *n = 335*	29.5 (29.2-29.8) *n = 440*
Mean BMI	*33.6*	*33.6*	*33.5*	*33.5*	*33.4*	*33.5*	*33.5*	*33.5*	*33.5*

35-	32.5 (32.2-32.9) *n = 428*	32.1 (31.8-32.5) *n = 358*	32.0 (31.6-32.4) *n = 302*	32.0 (31.7-32.3) *n = 416*	32.2 (31.8-32.5) *n = 280*	31.8 (31.4-32.2) *n = 261*	31.7 (31.3-32.1) *n = 247*	-	-
Mean BMI	*36.1*	*36.0*	*36.0*	*36.0*	*36.0*	*36.0*	*36.0*		
37.5-	34.3 (33.9-34.8) *n = 217*	-	-	-	-	-		-	-
Mean BMI	*38.5*								

Adjusted for age (5 year categories)

Values not shown for cells with less than 200 participants

Table S4 Mean (95% CI) body fat percentage by categories of BMI and physical activity in women in UK Biobank

Categories of BMI	Categories of physical activity (MET-hours/wk) <5	5-9.9	10-14.9	15-24.9	25-34.9	35-49.9	50-74.9	75-99.9	≥ 100
18.5-	24.4 (24.0-24.8) *n = 313*	23.5 (23.2-23.9) *n = 460*	23.5 (23.2-23.8) *n = 405*	23.1 (22.9-23.4) *n = 749*	22.7 (22.4-23.0) *n = 569*	22.5 (22.2-22.7) *n = 556*	22.[illegible] (2[illegible]-22.6) *n = [illegible]26*	22.3 (21.9-22.8) *n = 219*	22.3 (21.9-22.7) *n = 267*
Mean BMI	*19.4*	*19.3*	*19.4*	*19.4*	*19.4*	*19.4*	*19.4*	*19.3*	*19.4*
20-	28.4 (28.2-28.6) *n = 1657*	28.0 (27.9-28.2) *n = 2333*	27.8 (27.6-27.9) *n = 2378*	27.5 (27.4-27.6) *n = 4095*	27.2 (27.1-27.3) *n = 3115*	26.8 (26.7-27.0) *n = 3034*	26.7 (26.[illegible]-26.8) *n = 2746*	26.6 (26.4-26.8) *n = 1327*	26.2 (26.0-26.4) *n = 1156*
Mean BMI	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*	*21.4*
22.5-	32.6 (32.4-32.7) *n = 2872*	32.2 (32.1-32.3) *n = 4068*	32.0 (31.9-32.1) *n = 4014*	31.8 (31.7-31.9) *n = 6819*	31.4 (31.3-31.5) *n = 4981*	31.4 (31.3-31.5) *n = 4820*	31.2 (31.1-31.3) *n = 4496*	31.0 (30.8-31.2) *n = 2026*	30.7 (30.6-30.9) *n = 1998*
Mean BMI	*23.8*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*	*23.7*
25-	36.0 (35.9-36.2) *n = 2953*	35.7 (35.6-35.8) *n = 4016*	35.4 (35.3-35.6) *n = 3594*	35.4 (35.3-35.5) *n = 6034*	35.2 (35.1-35.3) *n = 4288*	35.1 (35.0-35.2) *n = 4069*	34.9 (34.8-35.0) *n = 3705*	34.8 (34.6-35.0) *n = 1692*	34.8 (34.6-35.0) *n = 1516*
Mean BMI	*26.2*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*	*26.1*
27.5-	39.0 (38.9-39.2) *n = 2353*	38.8 (38.6-38.9) *n = 2715*	38.5 (38.4-38.7) *n = 2370*	38.3 (38.2-38.5) *n = 3704*	38.3 (38.2-38.4) *n = 2616*	38.2 (38.1-38.4) *n = 2366*	38.[illegible] (37.9-38.2) *n = 2262*	38.0 (37.8-38.2) *n = 1008*	37.7 (37.5-37.9) *n = 879*
Mean BMI	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*	*28.6*
30-	41.5 (41.3-41.7) *n = 1625*	41.1 (40.9-41.3) *n = 1716*	41.1 (40.9-41.3) *n = 1424*	41.0 (40.9-41.2) *n = 2185*	40.8 (40.6-41.0) *n = 1366*	40.6 (40.4-40.8) *n = 1237*	40.8 (40.6-41.0) *n = 1181*	40.4 (40.1-40.7) *n = 564*	40.3 (40.0-40.6) *n = 468*
Mean BMI	*31.1*	*31.1*	*31.1*	*31.1*	*31.1*	*31.0*	*31.[illegible]*	*31.0*	*31.1*
32.5-	43.6	43.4	43.2	43.1	43.2	43.0	42.7	42.7	42.5

	(43.4-43.8)	(43.2-43.6)	(43.0-43.5)	(42.9-43.3)	(43.0-43.5)	(42.8-43.3)	(42.4-43.0)	(42.3-43.1)	(42.0-42.9)
	n = 1008	*n = 989*	*n = 774*	*n = 1149*	*n = 699*	*n = 651*	*n = 611*	*n = 260*	*n = 233*
Mean BMI	*33.6*	*33.6*	*33.6*	*33.6*	*33.6*	*33.5*	*33.[illegible]*	*33.5*	*33.5*
35-	45.3 (45.0-45.5) *n = 577*	45.2 (45.0-45.5) *n = 577*	44.9 (44.6-45.3) *n = 444*	45.0 (44.7-45.3) *n = 584*	44.9 (44.6-45.3) *n = 359*	44.9 (44.5-45.3) *n = 313*	44.8 (44.4-45.2) *n = 282*	-	-
Mean BMI	*36.1*	*36.1*	*36.0*	*36.1*	*36.1*	*36.1*	*36.0*		
37.5-	47.0 (46.6-47.3) *n = 368*	46.6 (46.2-47.0) *n = 303*	46.8 (46.3-47.2) *n = 207*	46.7 (46.3-47.1) *n = 316*	46.6 (46.1-47.0) *n = 205*	-		-	-
Mean BMI	*38.6*	*38.5*	*38.6*	*38.5*	*38.5*				
40-	48.3 (47.8-48.7) *n = 220*	-	-	-	-	-	-	-	-
Mean BMI	*41.1*								

Adjusted for age (5 year categories)

Values not shown for cells with less than 200 participants

Table S5 BMI and body fat percentage by sex and 5-year age category in UK Biobank

	n	BMI	Body fat percentage
Men			
< 45 years	15176	27.2 (4.0)	22.8 (5.5)
45-49 years	17569	27.4 (3.9)	23.5 (5.5)
50-54 years	18375	27.5 (3.9)	24.1 (5.5)
55-59 years	20580	27.3 (3.8)	24.6 (5.5)
60-64 years	26532	27.3 (3.7)	25.1 (5.4)
≥ 65 years	20671	27.1 (3.6)	25.6 (5.3)
Women			
< 45 years	17392	25.7 (4.8)	33.7 (7.0)
45-49 years	21848	26.0 (4.8)	34.3 (7.0)
50-54 years	23728	26.3 (4.7)	35.3 (6.7)
55-59 years	25329	26.3 (4.6)	35.9 (6.5)
60-64 years	31600	26.5 (4.4)	36.4 (6.3)
≥ 65 years	20343	26.5 (4.2)	36.7 (6.0)

Values are mean (SD)

Numbers of participants shown are for BMI within each age category, slightly fewer participants have information on body fat percentage

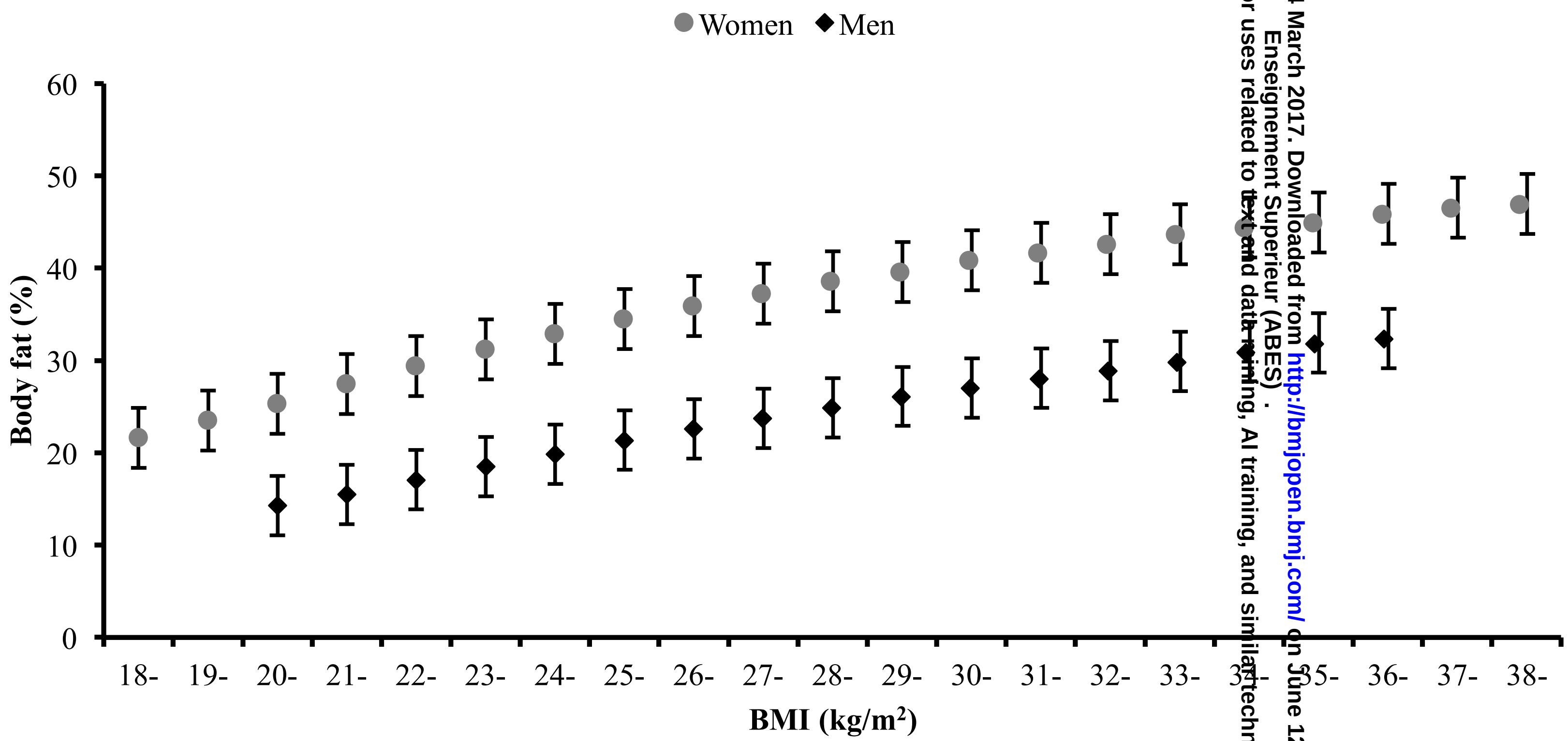

Figure S1 Body fat percentage by BMI for participants aged younger than 50 years in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

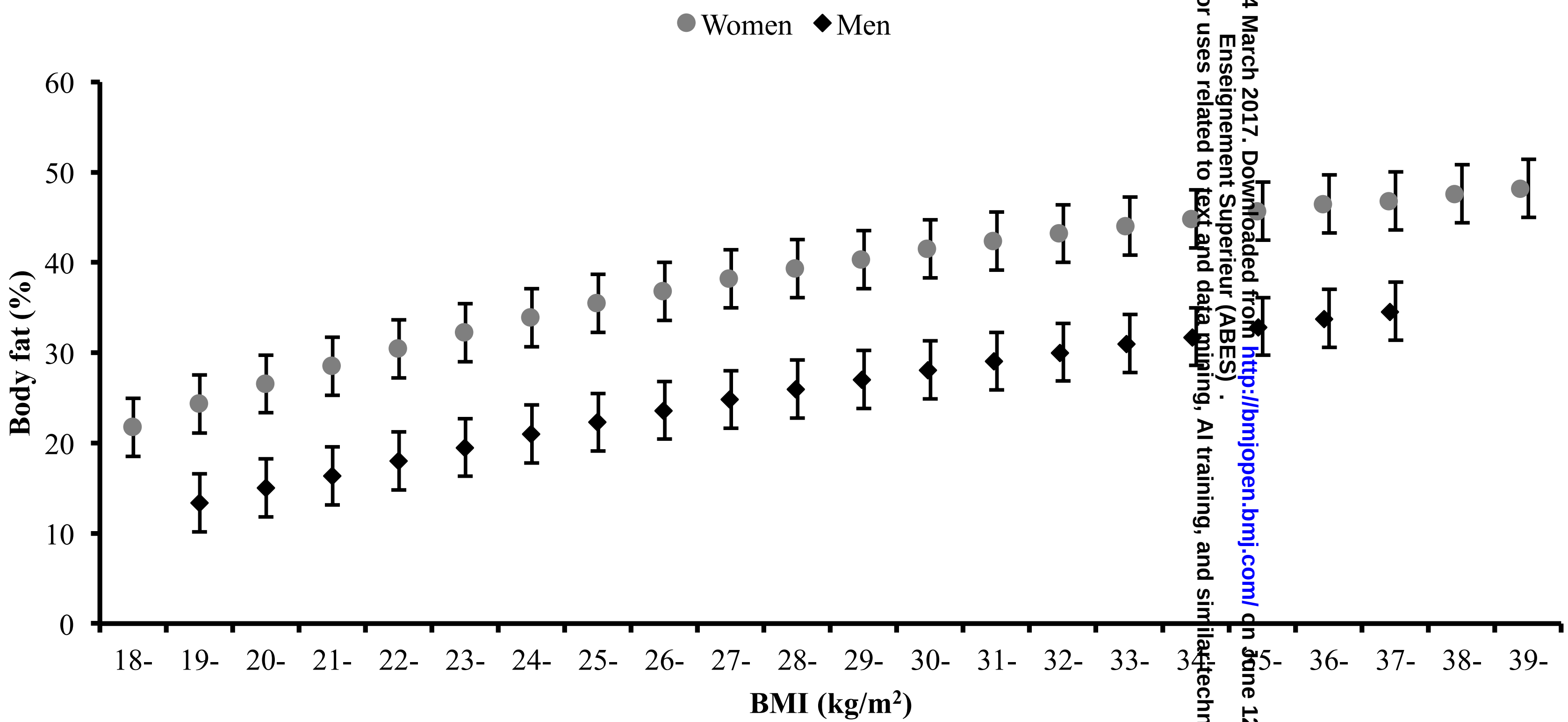

Figure S2 Body fat percentage by BMI for participants aged 50-59 years in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

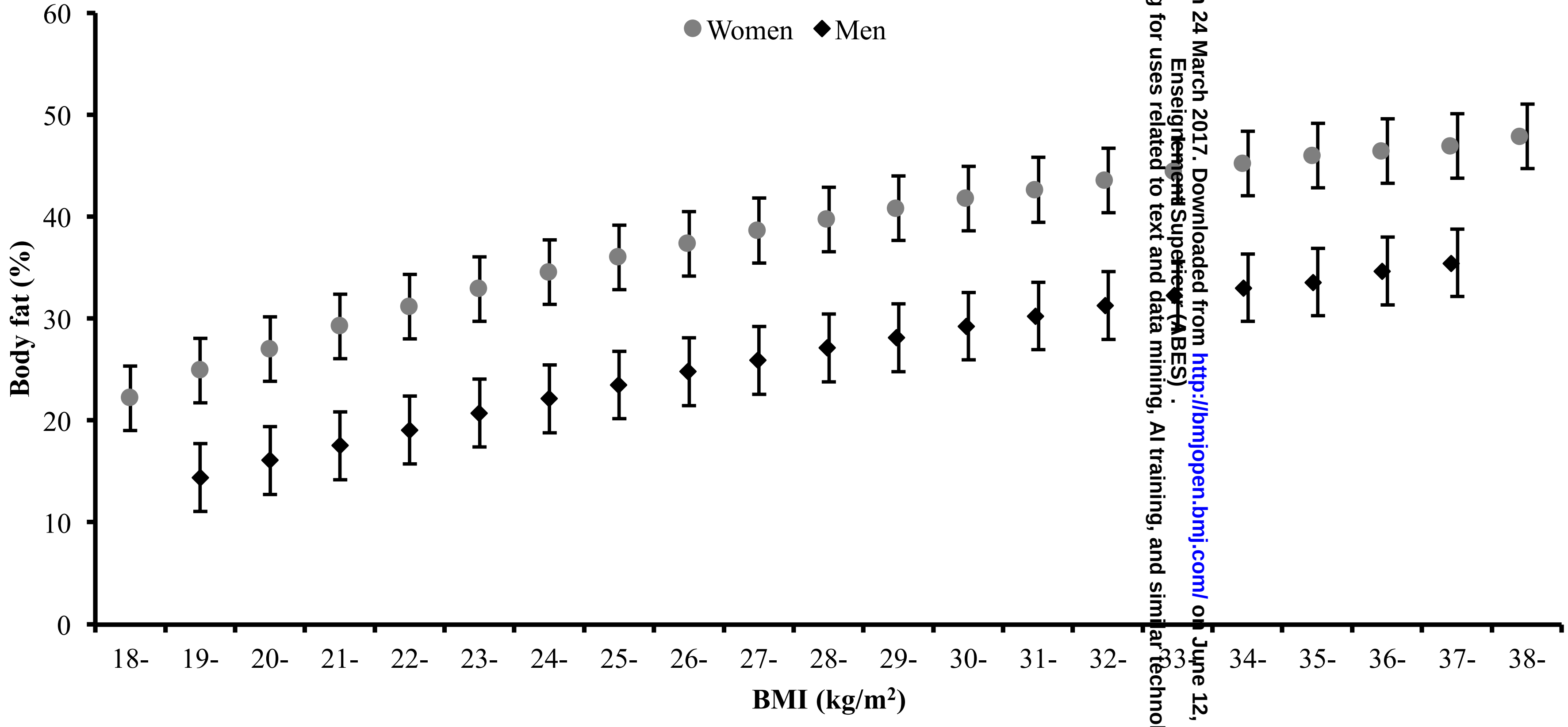

Figure S3 Body fat percentage by BMI for participants aged 60 years or older in UK Biobank
Values are mean body fat percentage by single-unit BMI categories
Error bars represent 1 SD either side of the mean
Estimates shown for cells with 200 or more participants

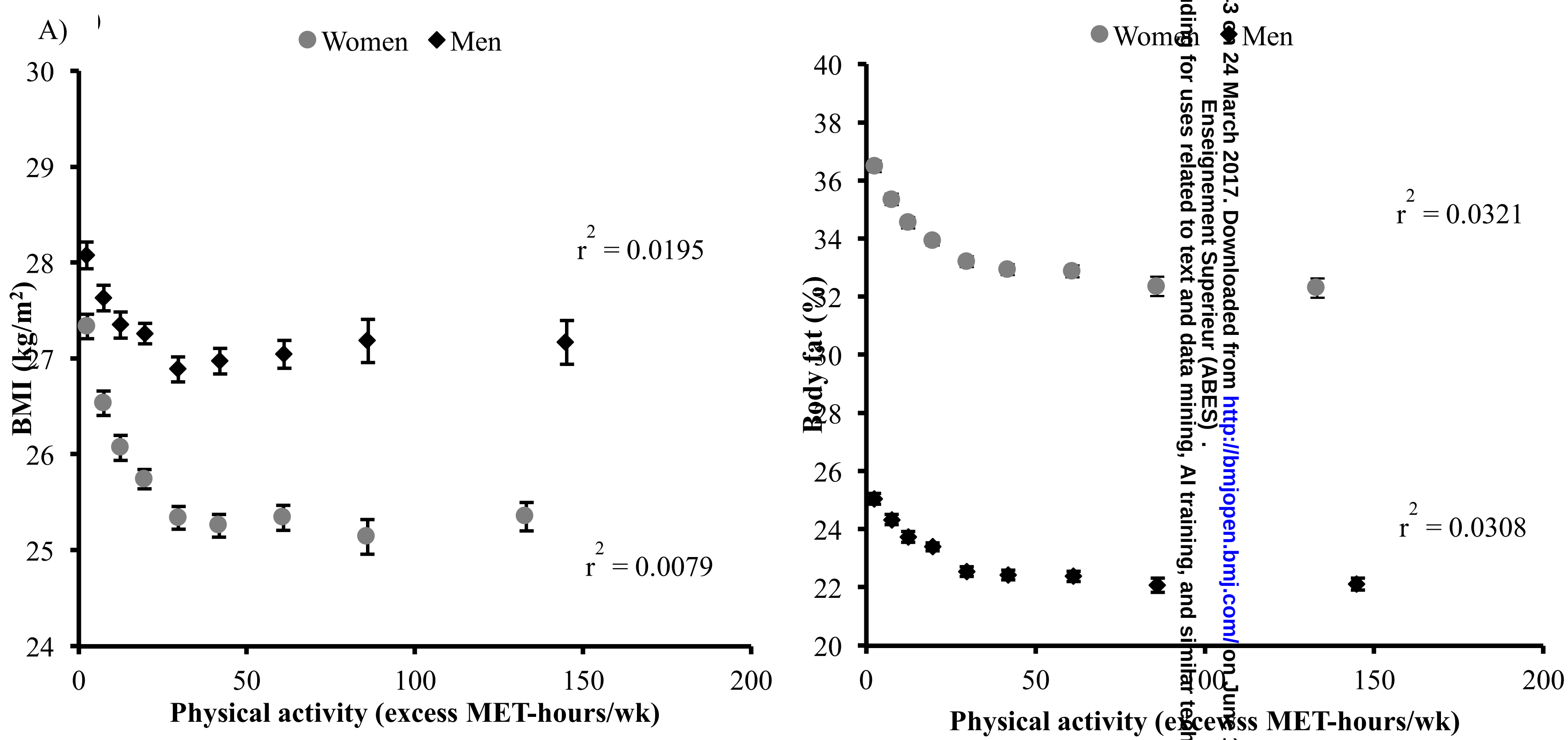

Figure S4 Mean BMI and body fat percentage by physical activity for participants aged younger than 50 years in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

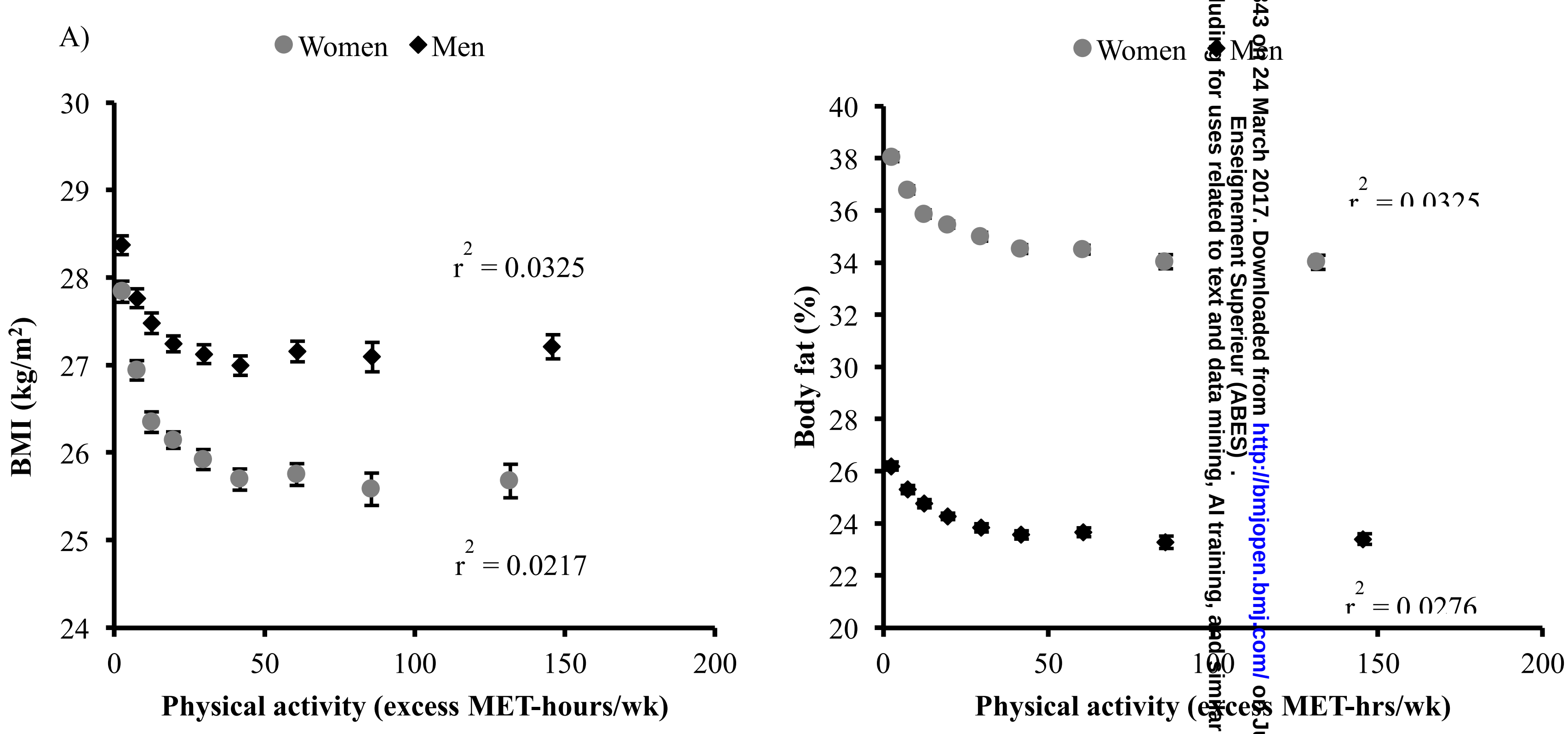

Figure S5 Mean BMI and body fat percentage by physical activity in participants aged 50-59 years in UK Biobank

Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)

Values are mean BMI and body fat percentage in the following categories of physcial activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category

Errors bars are 95% CI

Estimates shown for cells with 200 or more participants

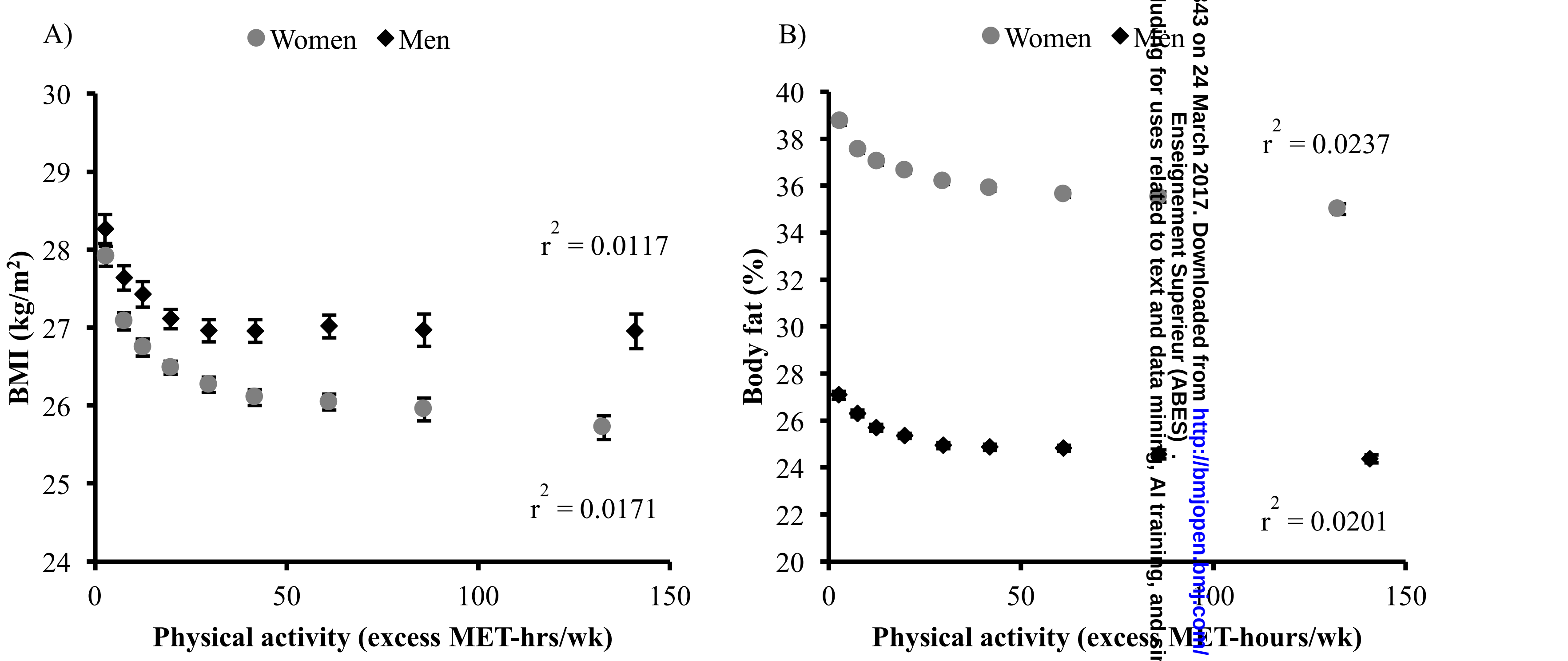

Figure S6 Mean BMI and body fat percentage by physical activity in participants aged 60 years or older in UK Biobank
Panel A: Mean BMI by physical activity (excess MET-hours/wk); Panel B: Mean body fat percentage by physical activity (excess MET-hrs/wk)
Values are mean BMI and body fat percentage in the following categories of physical activity: <5, 5-9.9, 10-14.9, 15-24.9, 25-34.9, 35-49.9, 50-74.9, 75-99.9, ≥ 100 excess MET-hrs per week, and are plotted at the value of the mean excess MET-hours/wk in each category
Errors bars are 95% CI
Estimates shown for cells with 200 or more participants

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract Title, and Pg 3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found Pg 3
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Pg 5
Objectives	3	State specific objectives, including any prespecified hypotheses Pg 5
Methods		
Study design	4	Present key elements of study design early in the paper Pg 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Pg 6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants Pg 8
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Pg 9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Pgs 6-8, and Footnotes for Table 1 and Table 2
Bias	9	Describe any efforts to address potential sources of bias Pg 10
Study size	10	Explain how the study size was arrived at Pg 8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Pg 9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding Pgs 9-10
		(*b*) Describe any methods used to examine subgroups and interactions Pgs 9-10
		(*c*) Explain how missing data were addressed Pg 8
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(*e*) Describe any sensitivity analyses Pg 9

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Pg 12, and Figure 1
		(b) Give reasons for non-participation at each stage Figure 1
		(c) Consider use of a flow diagram Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Pg 12, and Tables 1 and 2
		(b) Indicate number of participants with missing data for each variable of interest Footnotes for Tables 1 and 2
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures Tables 1 and 2.
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included Pgs 12-13
		(*b*) Report category boundaries when continuous variables were categorized Pgs 9-10
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Pgs 13-14
Discussion		
Key results	18	Summarise key results with reference to study objectives Pg 15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Pgs 15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence Pg 17
Generalisability	21	Discuss the generalisability (external validity) of the study results Pgs 16-17
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based Pg 18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.