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## Accelerometer compared with questionnaire measures of physical activity in relation to body size and composition: a large cross-sectional analysis of UK Biobank

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3 **Accelerometer compared with questionnaire measures of physical activity in relation to**  
4 **body size and composition: a large cross-sectional analysis of UK Biobank**  
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42 Abbreviations: body mass index (BMI), confidence interval (CI), dual-energy X-ray  
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44 absorptiometry (DXA), International Physical Activity Questionnaire (IPAQ), metabolic  
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46 equivalents (METs), standard deviation (SD)  
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## Abstract

**Objectives:** Previous studies of the association between physical activity and adiposity are largely based on self-reported physical activity and body mass index (BMI) from questionnaires, which are prone to inaccurate and biased reporting. We assessed the associations of accelerometer-measured compared to questionnaire-measured physical activity with BMI, waist circumference and body fat percent measured by bioelectrical impedance and dual-energy X-ray absorptiometry (DXA).

**Design:** Cross-sectional analysis of UK Biobank participants

**Setting:** UK Biobank assessment centers

**Participants:** 78,947 UK Biobank participants (35,955 men and 42,992 women) aged 40-70 at recruitment, who had physical activity measured by both questionnaire and accelerometer.

**Main outcome measures:** BMI, waist circumference and body fat percent measured by bioelectrical impedance and DXA

**Results:** Correlation between accelerometer and questionnaire measures of physical activity was low overall and even lower in participants with higher BMI and in older participants. Greater physical activity was associated with lower adiposity. Women in the top tenth of accelerometer-measured physical activity had a 4.8 (95% CI: 4.6, 5.0) kg/m<sup>2</sup> lower BMI, 8.1% (95% CI: 7.8, 8.3) lower body fat percent, and 11.9 (95% CI 11.4, 12.4) cm lower waist circumference while women in the top tenth of questionnaire-measured physical activity had a 2.5 (95% CI: 2.3, 2.7) kg/m<sup>2</sup> lower BMI, 4.3% (95% CI: 4.0, 4.5) lower body fat percent, and 6.4 (95% CI: 5.9, 6.9) cm lower waist circumference, compared to women in the bottom tenths. The patterns were similar in men and also similar with body fat percent measured by DXA compared to impedance.

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3 **Conclusion:** Our findings of approximately twofold stronger associations between physical  
4 activity and adiposity with objectively-measured compared to self-reported physical activity  
5 demonstrate substantial measurement error in self-reported physical activity, especially  
6 among participants with higher BMI and among older participants, and further emphasizes  
7 the need to incorporate objective measures in future studies.  
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17 **Strengths of limitations of this study:**  
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21 • Most large studies of physical activity are based on self-reported data from  
22 questionnaires, which are prone to inaccurate and potentially biased reporting.  
23  
24 • This study is by far the largest study to compare associations between physical  
25 activity objectively measured by accelerometer and self-reported physical activity in  
26 relation to various measures of adiposity, including body fat percent assessed by  
27 bioelectrical impedance and dual energy x-ray absorptiometry.  
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29 • Due to the cross-sectional nature of this study, we cannot assess to what extent  
30 physical activity is causally related to adiposity.  
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## INTRODUCTION

The prevalence of overweight and obesity is high worldwide and is associated with increased risk of various conditions including heart disease, stroke, hypertension, diabetes, and some cancers (1, 2). Although physical activity is generally accepted to be important for prevention of weight gain, achievement of modest weight loss, and prevention of weight regain after weight loss (3), randomized controlled trials have shown inconsistent results, perhaps partly due to limited duration of interventions and difficulty in long-term adherence to exercise regimens (4), and previous large-scale observational studies are mostly based on self-reported physical activity from questionnaires, which are prone to both inaccurate reporting and reporting bias (5).

Prior studies have demonstrated low to moderate correlation between self-reported and objective accelerometer measures of physical activity (6, 7). Self-reported and accelerometer-measured physical activity capture different aspects of physical activity with limitations unique to each (7). However, research methods utilizing more objective measures of physical activity, along with more detailed measures of body fat, are needed to reduce measurement error and more accurately characterize the association between physical activity and adiposity.

We examined the association between physical activity and adiposity, with accelerometer-measured compared to self-reported physical activity in nearly 80,000 participants. These associations were assessed using various measures of adiposity, including BMI, waist circumference, and body fat percent measured by both bioelectrical impedance and dual-energy X-ray absorptiometry (DXA). We also explored how the associations vary by age.

## METHODS

### Data source

Data were obtained from UK Biobank. Details of UK Biobank design, rationale, and survey methods have been described elsewhere (8). Information on data available and access procedures are described on the study website (<http://www.ukbiobank.ac.uk/>). UK Biobank has approval from the National Information Governance Board for Health & Social Care in England and Wales, the North West Multi-centre Research Ethics Committee, and the Community Health Index Advisory Group in Scotland. Written informed consent was provided by all participants.

### Study participants

The complete UK Biobank dataset includes 502,617 UK adults (229,164 men and 273,453 women) between 40 to 70 years of age at recruitment during 2006 to 2010. During the baseline assessment center visit, participants completed a touchscreen questionnaire which included questions on socio-demographics, lifestyle, health and medical history, and sex-specific factors. The present study was restricted to participants with available accelerometer data (n=103,705). Participants were excluded if they did not have at least 72 hours of data and also data in each one-hour period of the 24-hour cycle across multiple days (n=6,995). Participants were also excluded if they had insufficient data for calibration (n=4). Participants who had missing data on any of the physical activity variables used in our analyses were excluded (n=15,999). Participants who reported physical activity greater than an average of 16 hours per day (n=620) were also excluded as recommended by the International Physical Activity Questionnaire (IPAQ) scoring guidelines, which can be accessed at <file:///H:/Downloads/GuidelinesforDataProcessingandAnalysisoftheInternationalPhysicalActivityQuestionnaireIPAQShortandLongForms.pdf>. Finally, participants with missing data on

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3 BMI (n=146), body fat percent (n=988), and waist circumference (n=6) were excluded. The  
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5 analyses included 35,955 men and 42,992 women (**Supplementary Figure 1**).  
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#### 8 Self-reported physical activity 9

10 Physical activity questions from the baseline questionnaire captured the frequency and  
11 duration of three intensities of activity (walking, moderate, and vigorous). Participants were  
12 asked how many days per week they typically engaged in each category of activity. For each  
13 category in which an answer of one or more days was given, the participant was subsequently  
14 asked the number of minutes on average spent on the activity per day. Questions were  
15 adapted from the IPAQ, a validated survey instrument (9), and are listed in **Supplementary**  
16 **Table 1**. Metabolic equivalents (METs) were used to quantify physical activity; 1 MET is  
17 expended by sitting quietly for 1 hour, and the MET value reflects the ratio of energy  
18 expended per kilogram of body weight per hour to that expended when sitting quietly (10).  
19 The number of minutes per day engaged in each level of activity was multiplied by the  
20 respective MET score for the corresponding level of activity (3.3 for walking, 4.0 for  
21 moderate physical activity, and 8.0 for vigorous physical activity). MET minutes per day  
22 were converted to MET hours per week. The total amount of METs was calculated by  
23 summing total METs from the walking, moderate, and vigorous activity levels. Following  
24 IPAQ scoring guidelines, physical activity of less than 10 minutes per day for any category  
25 was recoded to 0.  
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#### 45 Accelerometer-measured physical activity 46

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49 A total of 236,519 participants, all of whom had provided a valid email address, were  
50 invited to participate in a seven day accelerometer study between February 2013 and  
51 December 2015 (on average, approximately 5.5 years after recruitment). Starting in June  
52 2013, participants were sent wrist-worn triaxial accelerometers (Axivity AX3, Newcastle  
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upon Tyne, UK) that were programmed to capture three-dimensional acceleration data at 100 Hz with a dynamic range of  $\pm 8$  g. Participants were also given instructions to wear the accelerometer on their dominant wrist continuously for seven days and then to send the device to the coordinating center using the provided prepaid envelope. Further details on data collection, processing, and analysis can be found elsewhere (11).

### Anthropometry and body composition

At the UK Biobank baseline interview, trained staff measured standing height using the Seca 202 device (Seca, Hamburg, Germany). BMI was calculated by dividing weight (kg) by the square of standing height ( $m^2$ ). The Wessex non-stretchable sprung tape measure (Wessex, United Kingdom) was used to measure waist circumference. The Tanita BC-418MA body composition analyzer (Tanita, Tokyo, Japan) was used to measure body fat percent using bioelectrical impedance. DXA was used to measure fat percent on a subset of participants beginning in 2014 using the GE-Lunar iDXA (GE Healthcare, Chicago, USA).

### Statistical analyses

Baseline characteristics were summarized by physical activity (least active fifth, most active fifth, and overall) separately for men and women. Since self-reported physical activity was not normally distributed, Spearman's correlation coefficients were used to measure the strength of correlations between self-reported and accelerometer-measured physical activity in the overall population and in subgroups based on sociodemographic characteristics.

Self-reported and accelerometer-measured physical activity were categorized into tenths and the median value within each category of physical activity is shown in the figures. The associations of physical activity and adiposity measures were examined using multivariable linear regression, separately in men and women. Analyses comparing the association of

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3 accelerometer-measured physical activity with body fat percent, measured by bioelectrical  
4 impedance and DXA were restricted to participants with both measures. Likelihood ratio tests  
5 were used to assess whether the associations between physical activity and adiposity were  
6 modified by age (<55 years or 55+ years), separately for self-reported and accelerometer-  
7 measured physical activity.  
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14 Covariates were determined a priori and were 5-year age at recruitment categories,  
15 socioeconomic status as indicated by fifths of Townsend deprivation index (12), educational  
16 qualifications, employment status, smoking status (never, previous, current), and alcohol  
17 intake frequency. Analyses in women were additionally adjusted for parity (nulliparous, 1, 2,  
18 3, 4 or more births) and hormone replacement therapy use (never, previous, current). As a  
19 covariate, educational qualification was grouped into the following categories: vocational  
20 qualifications, national exams at age 16 (O levels, GCSEs, CSEs, or equivalent), optional  
21 national exams at ages 17-18 years (A levels, AS levels, or equivalent), and college or  
22 university degree. Employment status was categorized as paid or self-employed, retired,  
23 looking after home and/or family, unemployed, doing unpaid or voluntary work, unable to  
24 work due to sickness or disability, and student. Alcohol intake was categorized as never,  
25 special occasions only, 1-3 times a month, 1-2 times a week, 3-4 times a week, and daily or  
26 almost daily.  
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43 Missing data were grouped in a separate unknown category for each covariate. There were  
44 less than 1% missing data for all covariates except for educational qualifications (7.4%  
45 missing data). To assess the impact of missing values, a sensitivity analysis restricted to  
46 participants with known values for all covariates was conducted. We also conducted  
47 sensitivity analyses to assess the impact of excluding participants who reported long-term  
48 illness, disability or infirmity, participants who reported fair or poor health rather than  
49 excellent or good health, and participants whose jobs usually or always required heavy  
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3 manual work. Analyses were conducted using STATA, version 15.0 (Stata Corp LP, College  
4 Station, TX).  
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#### 7 Patient and public involvement

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10 This study did not involve patients and the public.  
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## 13 RESULTS

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16 Characteristics of the study population by least active and most active fifth of  
17 accelerometer-measured physical activity are shown in **Table 1**. Mean accelerometer-  
18 measured physical activity was 27.6 (standard deviation [SD] 8.7) milli-gravity in men and  
19 28.7 (SD 8.0) milli-gravity in women. The most active participants were on average younger  
20 and had lower values for all body size and composition variables. They were more likely to  
21 have a college or university degree, be employed rather than retired, have an active job, and  
22 consume alcohol at least weekly. The least active participants were more likely to be ever  
23 smokers and were also more likely to have a long-standing illness or disability. The  
24 correlation between questionnaire and accelerometer-measured physical activity was 0.24  
25 (95% confidence interval [CI]: 0.23, 0.25) in men (**Supplementary Table 2**) and 0.22 (95%  
26 CI: 0.21, 0.23) in women (**Supplementary Table 3**). The correlations were comparatively  
27 higher in participants who were younger and in participants who had lower BMI. The  
28 correlations were lower among participants who reported that their job usually or always  
29 involved heavy manual work and/or mainly walking or standing.  
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48 The inverse associations between physical activity and all measures of adiposity were  
49 linear and approximately twofold larger in models that used accelerometer-measured rather  
50 than self-reported physical activity. Since there was heterogeneity in the associations between  
51 both self-reported and accelerometer-measured physical activity and adiposity by sex  
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( $P < 0.001$ ), separate analyses were performed in men and women. The mean differences in BMI and body fat percent were greater in women compared to men. Comparing the top to bottom tenth of accelerometer-measured physical activity, the difference in BMI was 4.8 (95% CI: 4.6, 5.0)  $\text{kg/m}^2$  in women and 3.6 (95% CI: 3.4, 3.8)  $\text{kg/m}^2$  in men (**Figure 1, Supplementary Table 4**).

Women in the top tenth of accelerometer-measured physical activity had an 8.1% (95% CI: 7.8, 8.3) lower body fat percent while women in the top tenth of self-reported physical activity had a 4.3% (95% CI: 4.0, 4.5) lower body fat percent, compared to those in the bottom tenth of physical activity. Men in the top tenth of accelerometer-measured physical activity had a 6.0% (95% CI: 5.7, 6.2) lower body fat percent while men in the top tenth of self-reported physical activity had a 3.6% (95% CI: 3.3, 3.8) lower body fat percent, compared to those in the bottom tenth (**Figure 1, Supplementary Table 4**).

Associations between physical activity and waist circumference were of similar magnitude in men and women, with an approximately twofold larger inverse association between waist circumference and physical activity when measured by accelerometer rather than questionnaire (**Figure 1, Supplementary Table 4**).

The results of sensitivity analyses excluding participants who had any missing values, reported a long-term illness or disability, reported a health rating worse than “good”, or whose jobs usually or always required heavy manual work did not materially differ from the main findings.

**Figure 2 and Supplementary Table 5** show the associations between accelerometer-measured physical activity and bioelectrical impedance-measured body fat percent at baseline (2006-2010) compared to body fat percent measured by DXA starting in May 2014. Body fat percent by impedance at baseline was lower than body fat percent by DXA, measured on

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3 average seven years later. For both measures, there was a linear dose-response association  
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5 between physical activity and body fat percent in both men and women. The inverse  
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7 associations were stronger when body fat percent was measured by DXA. Compared to the  
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9 least active women, the most active women had an 8.8% (95% CI: 7.7, 10.0) lower DXA-  
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11 measured body fat percent and a 7.0% (95% CI: 5.9, 8.1) lower impedance-measured body  
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13 fat percent (**Figure 2 and Supplementary Table 5**).

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16 Associations between physical activity and measures of adiposity by age group are shown  
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18 in **Figure 3** for men and **Figure 4** for women. For a given level of accelerometer-measured  
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20 physical activity, the older participants (over age 55) had a slightly lower BMI but a higher  
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22 body fat percent compared to their younger counterparts. For women, there was heterogeneity  
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24 by age in the association between self-reported physical activity and body fat percent  
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26 ( $P=0.03$ ) but there was no heterogeneity by age when physical activity was measured by  
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28 accelerometer ( $P=0.27$ ).

## 31 32 DISCUSSION

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35 In this large cross-sectional study of nearly 80,000 participants, we found that associations  
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37 between physical activity and BMI, body fat percent, and waist circumference were stronger  
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39 when physical activity was measured by accelerometer compared to questionnaire self-  
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41 reports. Body fat percent measured by DXA at follow-up showed a slightly stronger  
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43 association with physical activity compared to body fat percent measured by bioelectrical  
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45 impedance at baseline, but the overall pattern of association was similar. The correlation  
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47 between accelerometer-measured and self-reported physical activity was lower in participants  
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49 with higher BMI and in older participants.

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52 Our analyses based on accelerometer-measured physical activity suggest an approximately  
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54 linear inverse association between physical activity and adiposity, with the most active  
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3 participants having the lowest BMI, body fat percent, and waist circumference. In contrast,  
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5 the analyses in the same participants based on self-reported physical activity suggest a  
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7 comparatively small further benefit of physical activity greater than 50 MET-hours a week on  
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9 adiposity.  
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12 We have previously suggested that the steeper relationship between physical activity and  
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14 lower adiposity within the lower range of physical activity could be due to either a  
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16 comparatively larger benefit of physical activity for those who are relatively inactive or  
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18 measurement error from over-reporting of high physical activity (13). The present analyses  
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20 demonstrating an approximately linear dose-response relationship between accelerometer-  
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22 measured physical activity and adiposity supports the latter explanation and further suggests  
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24 that over-reporting of total physical activity contributed to the low overall correlation  
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26 between self-reported and accelerometer-measured physical activity. Although wrist  
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28 accelerometer-measured physical activity has limitations, such as measuring movement of  
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30 only one part of the body and the inability to reliably capture activities such as cycling (7), it  
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32 has the major advantage of eliminating both inaccurate reporting that leads to random error as  
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34 well as reporting bias that may vary by sociodemographic characteristics.  
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40 Measurement error in the self-reported data results in misclassification of individuals by  
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42 physical activity status. We used the IPAQ short form data processing rules since the UK  
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44 Biobank questionnaire did not comprehensively cover domain-specific activities, but it is still  
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46 likely that lower intensity activities were underreported and reported less accurately (14). In  
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48 contrast, the accelerometers were worn for 24 hours a day, over 7 days. Therefore, the lower  
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50 correlation between self-reported and accelerometer-measured physical activity in older  
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52 participants and the heterogeneity by age seen only with the self-reported data may be  
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54 explained by the observation that, in older adults, a greater proportion of physical activity is  
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56 of lower intensity (15).  
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3 Individuals with higher body fat percent may report moderate and strenuous physical  
4 activity less accurately than leaner individuals, based on comparisons between self-reported  
5 physical activity and energy expenditure estimated from whole-room indirect calorimeter  
6 (16). In agreement with some previous studies, we found that the correlation between  
7 physical activity measured by questionnaire and accelerometer-measured physical activity  
8 was greater for those with lower BMI (7). This suggests that measurement error of self-  
9 reported physical activity may be greater in overweight and obese BMI groups.  
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18 We, like several prior studies, found stronger associations between accelerometer-  
19 measured physical activity and all measures of adiposity in women compared to men (17-19).  
20 This may partly be due to the fact that, in the present study, men were on average objectively  
21 less physically active than women. Differences in fat metabolism may also play a role, with a  
22 greater proportion of energy derived from lipolysis during exercise in women compared to  
23 men (20, 21).  
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33 To our knowledge, the present study is the largest to date comparing accelerometer-  
34 measured and self-reported physical activity in relation to direct measures of body fat,  
35 although our results are consistent with prior, smaller studies that suggest a stronger  
36 association between adiposity and accelerometer-measured compared to self-reported  
37 physical activity (17, 19, 22-24). A major strength of this study is the availability of both  
38 accelerometer-measured physical activity and body fat by impedance in nearly 80,000  
39 participants, together with data on body fat assessed by DXA in over 2,400 participants.  
40 Additionally, the accelerometers used in this study were waterproof (11), overcoming a  
41 limitation of prior studies where the devices had to be removed for water-based activities  
42 (19).  
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3 While self-reported physical activity was available at baseline in these data,  
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5 accelerometer-measured physical activity was assessed only 3-5 years after end of  
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7 recruitment, which raises the question of whether higher adiposity at baseline predicts lower  
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9 physical activity levels (25) rather than physical activity determining adiposity. However, our  
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11 analysis of accelerometer-measured physical activity in relation to DXA-measured body fat  
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13 percent, which was assessed within the same time frame as accelerometer-measured physical  
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15 activity, showed similar results to the main analysis based on body fat percent assessed by  
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17 impedance at baseline. Other limitations include the lack of data on total energy intake for the  
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19 whole cohort. Due to the cross-sectional nature of this study, we cannot assess to what extent  
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21 physical activity is causally related to adiposity. Highly active individuals may also be more  
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23 likely to maintain appropriate target energy intake, for example. Although the UK Biobank  
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25 cohort may not be representative of the sampling population, results of associations between  
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27 exposures and health outcomes may be generalizable and would not necessarily require the  
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29 study population to be representative if the biological basis of the exposure-disease  
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31 relationship is shared.  
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36 In conclusion, our findings based on objective accelerometer data indicate a stronger  
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38 relationship between physical activity and adiposity than previously thought. Comparison of  
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40 results with physical activity measured by questionnaire and accelerometer suggest  
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42 substantial measurement error in self-reported physical activity, emphasizing the need to  
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44 incorporate objective measures of physical activity in future studies.  
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51  
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**Contributors:** WG, TJK, and GKR were responsible for study concept, design of the study, interpretation of the data, and manuscript writing. WG had primary responsibility for statistical analysis and final content. All authors reviewed and approved the final manuscript.

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## Figure legends

**Figure 1.** Association of self-reported and accelerometer-measured physical activity with adiposity variables in UK Biobank

Association of A) accelerometer-measured and B) self-reported physical activity with BMI

Association of C) accelerometer-measured and D) self-reported physical activity with body fat percent

Association of E) accelerometer-measured and F) self-reported physical activity with waist circumference

Physical activity was grouped into tenths, separately in men and women.

Adjusted geometric means (from linear regression models) for BMI, body fat percent, and waist circumference are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by squares for men and triangles for women.

These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use.

The figure shows point estimates and 95% confidence intervals.

Abbreviations: BMI, body mass index; MET, metabolic equivalent

**Figure 2.** Association of accelerometer-measured physical activity with body fat percent measured by impedance and DXA in UK Biobank A) men and B) women

Physical activity was grouped into fifths, separately in men and women.

Adjusted geometric means (from linear regression models) for body fat percent are plotted against the median value within each fifth of accelerometer-measured physical activity.

Adjusted geometric means are represented by diamonds for body fat percent measured by impedance and circles for body fat percent measured by DXA.

These analyses are restricted to participants with measures of body fat percent by both impedance and DXA. Analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use.

The figure shows point estimates and 95% confidence intervals.

Abbreviations: DXA, dual-energy X-ray absorptiometry

**Figure 3.** Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank men

Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI.

Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent.

Physical activity was grouped into tenths.

Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-

measured physical activity. Adjusted geometric means are represented by diamonds for those under age 55 and squares for those ages 55 or older.

These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency.

The figure shows point estimates and 95% confidence intervals.

Abbreviations: BMI, body mass index; MET, metabolic equivalent

**Figure 4.** Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank women

Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI.

Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent.

Physical activity was grouped into tenths.

Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for those under age 55 and squares for those ages 55 or older.

These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency, parity, and hormone replacement therapy use.

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3 The figure shows point estimates and 95% confidence intervals.  
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6 Abbreviations: BMI, body mass index; MET, metabolic equivalent  
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11 **Supplementary Figure 1.** Flowchart illustrating the application of exclusion criteria for the  
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13 current study in UK Biobank  
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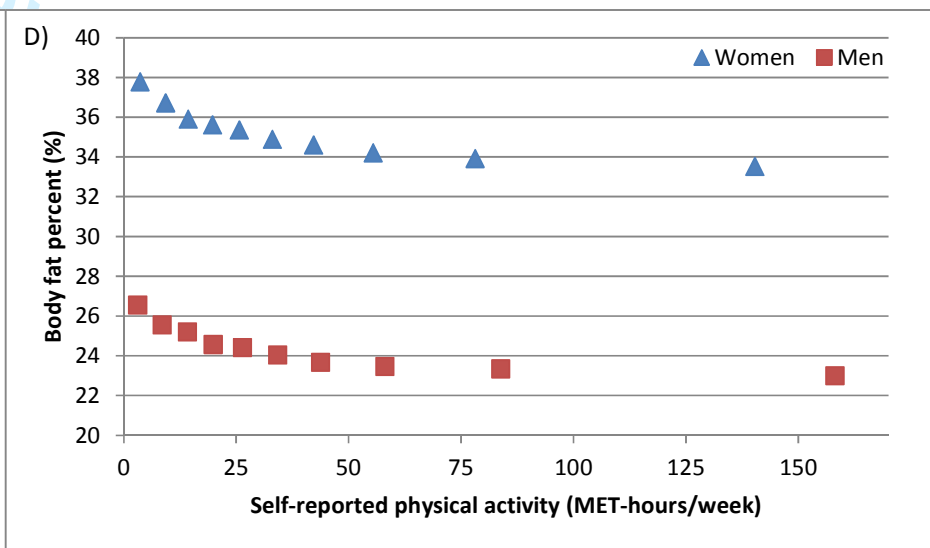
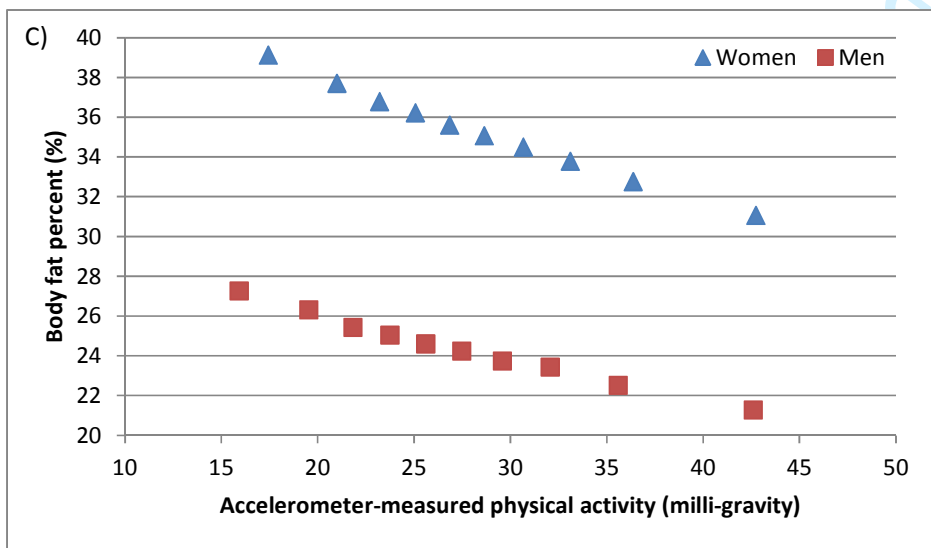
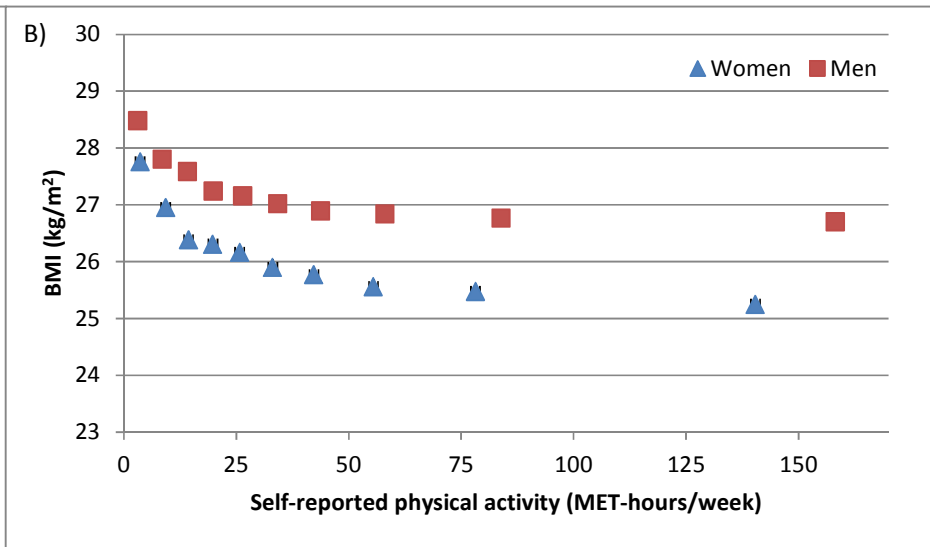
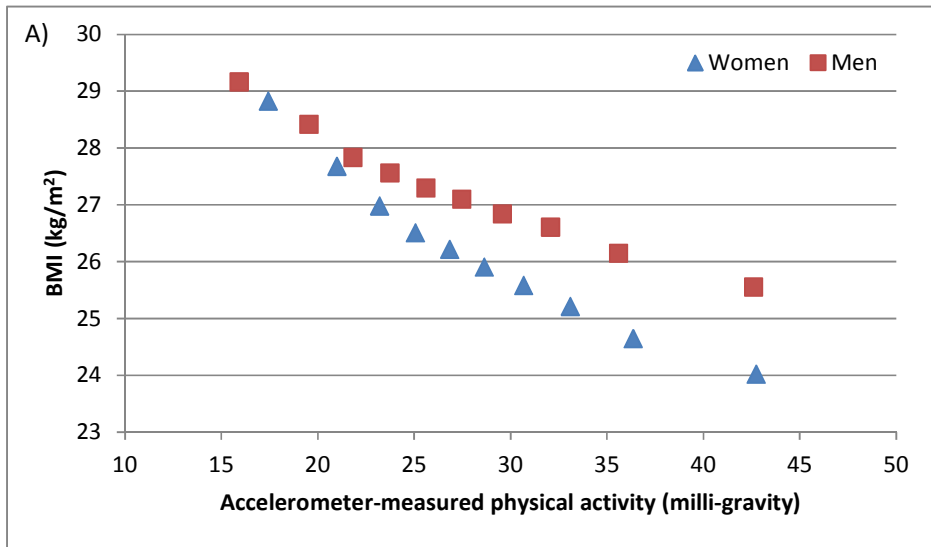
**Table 1. Characteristics of the UK Biobank study population, according to fifths of accelerometer-measured physical activity.**

|  | Least active men    | Most active men     | All men           | Least active women  | Most active women   | All women         |
|--|---------------------|---------------------|-------------------|---------------------|---------------------|-------------------|
|  | <20.8 milli-gravity | ≥33.7 milli-gravity |                   | <22.2 milli-gravity | ≥34.6 milli-gravity |                   |
| <b>Number of participants</b>  | 7,202               | 7,186               | 35,955            | 8,606               | 8,595               | 42,992            |
| <b>Age at recruitment (years), mean (SD)</b>                               | 59.7 (7.0)          | 53.4 (7.7)          | 56.7 (7.9)        | 58.0 (7.4)          | 52.6 (7.4)          | 55.3 (7.7)        |
| <b>Lowest fifth of socioeconomic status</b>                                | 1,520 (21.1%)       | 1,351 (18.8%)       | 6,800 (18.9%)     | 1,897 (22.0%)       | 1,699 (19.8%)       | 8,744 (20.3%)     |
| <b>Accelerometer-measured physical activity (milli-gravity), mean (SD)</b> | 17.5 (2.6)          | 40.5 (7.8)          | 27.6 (8.7)        | 18.9 (2.7)          | 40.6 (6.3)          | 28.7 (8.0)        |
| <b>Self-reported physical activity (MET-hours/week), median (IQR)</b>      | 20.7 (9.0, 42.6)    | 44.2 (23.7, 80.9)   | 29.9 (14.2, 58.1) | 21.3 (9.9, 41.7)    | 40.2 (21.8, 73.2)   | 29.3 (14.4, 55.3) |
| <b>Height (cm), mean (SD)</b>  | 176.3 (6.8)         | 176.4 (6.6)         | 176.5 (6.6)       | 163.2 (6.3)         | 163.7 (6.1)         | 163.5 (6.2)       |
| <b>Weight (kg), mean (SD)</b>  | 89.4 (15.4)         | 80.8 (11.4)         | 84.9 (13.5)       | 75.5 (15.6)         | 65.0 (10.3)         | 69.9 (13.2)       |
| <b>BMI (kg/m<sup>2</sup>), mean (SD)</b>                                   | 28.8 (4.6)          | 25.9 (3.3)          | 27.2 (4.0)        | 28.3 (5.7)          | 24.3 (3.7)          | 26.2 (4.8)        |
| <b>Body fat percent (%), mean (SD)</b>                                     | 27.0 (5.6)          | 21.7 (5.4)          | 24.4 (5.7)        | 38.7 (6.6)          | 31.7 (6.4)          | 35.3 (6.8)        |
| <b>Waist circumference (cm), mean (SD)</b>                                 | 100.1 (11.7)        | 90.9 (9.3)          | 95.4 (10.8)       | 87.9 (13.3)         | 77.6 (9.5)          | 82.4 (11.7)       |
| <b>College or university degree</b>  | 3,018 (41.9%)       | 3,365 (46.8%)       | 16,709 (46.5%)    | 3,586 (41.7%)       | 4,060 (47.2%)       | 19,214 (44.7%)    |
| <b>Current employment status</b>   |                     |                     |                   |                     |                     |                   |
| Paid employment/self-employed  | 3,608 (50.1%)       | 5,420 (75.4%)       | 22,942 (63.8%)    | 4,401 (51.1%)       | 6,101 (71.0%)       | 26,693 (62.1%)    |
| Retired  | 3,107 (43.1%)       | 1,451 (20.2%)       | 11,361 (31.6%)    | 3,517 (40.9%)       | 1,591 (18.5%)       | 12,710 (29.6%)    |
| Other  | 487 (6.8%)          | 315 (4.4%)          | 1,652 (4.6%)      | 688 (8.0%)          | 903 (10.5%)         | 3,589 (8.3%)      |
| <b>Job involves mainly walking/standing<sup>a</sup></b>                    | 707 (19.6%)         | 1,742 (32.1%)       | 5,574 (24.3%)     | 893 (20.3%)         | 1,926 (31.6%)       | 6,648 (24.9%)     |
| <b>Job involves heavy manual work<sup>b</sup></b>                          | 272 (7.5%)          | 912 (16.8%)         | 2,335 (10.2%)     | 170 (3.9%)          | 576 (9.4%)          | 1,567 (5.9%)      |
| <b>Weekly or more frequent alcohol intake</b>                              | 5,545 (77.0%)       | 5,989 (83.3%)       | 29,421 (81.8%)    | 5,295 (61.5%)       | 6,292 (73.2%)       | 29,829 (69.4%)    |
| <b>Ever smoker</b>   | 3,801 (52.8%)       | 3,126 (43.5%)       | 16,964 (47.2%)    | 3,583 (41.6%)       | 3,212 (37.4%)       | 16,936 (39.4%)    |
| <b>Long-standing illness or disability</b>                                 | 3,089 (42.9%)       | 1,543 (21.5%)       | 10,825 (30.1%)    | 3,145 (36.5%)       | 1,449 (16.9%)       | 1,0685 (24.9%)    |

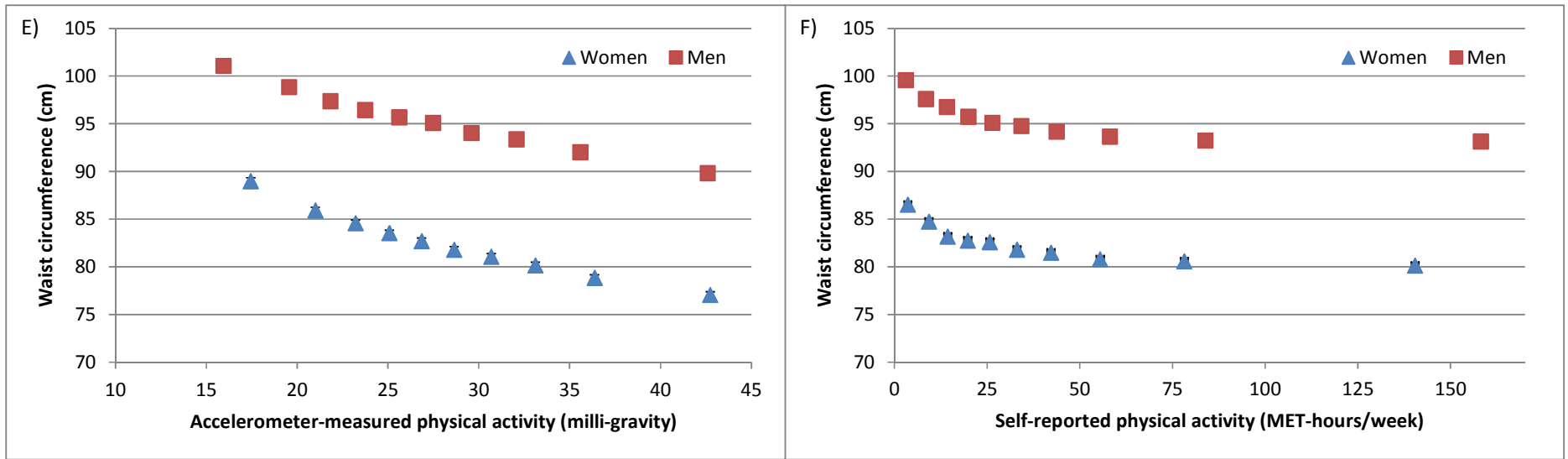
<sup>a</sup> Participants who reported their work “usually” or “always” involved walking or standing for most of the time

<sup>b</sup> Participants who reported their work “usually” or “always” involved heavy manual or physical work for most of the time

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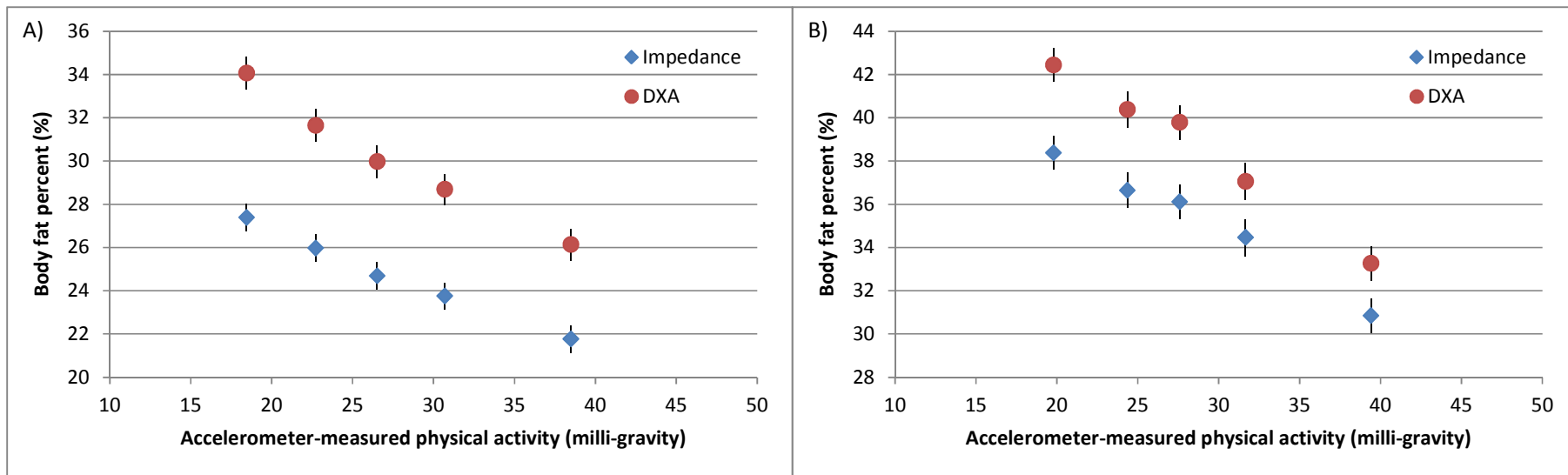


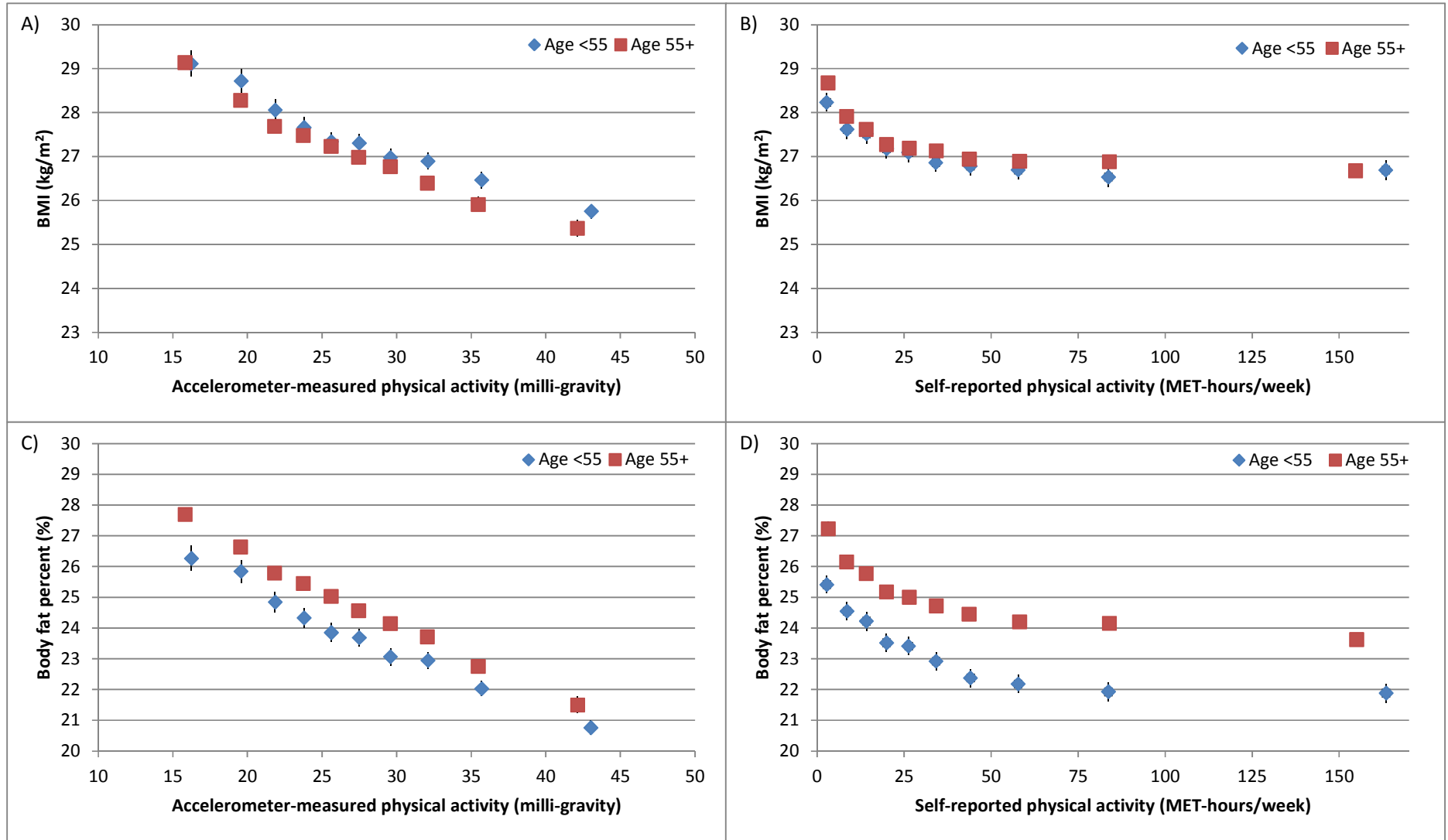


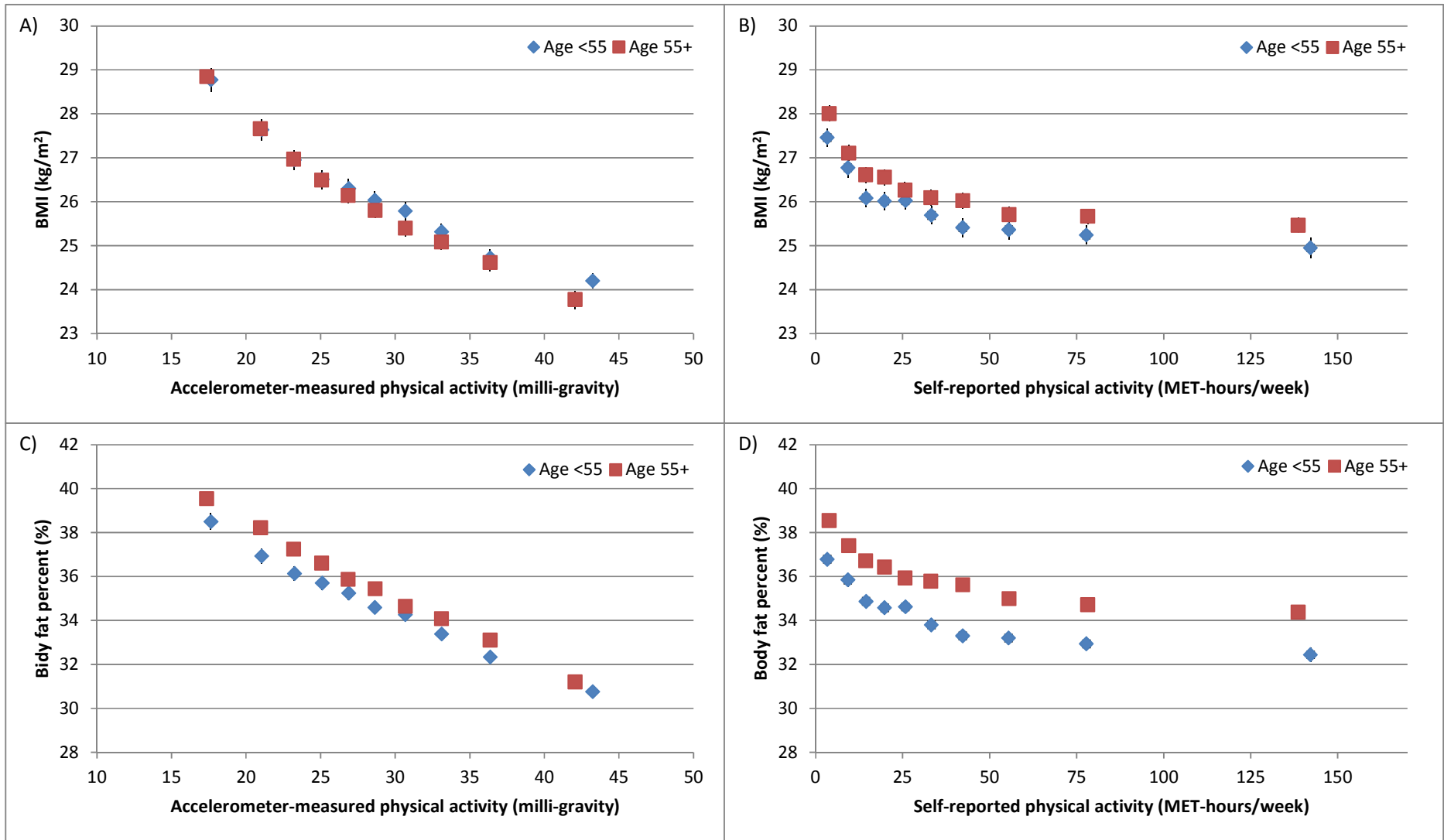


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**Supplementary Table 1. Physical activity questions from the UK Biobank baseline questionnaire**

| Question   | Potential Responses  |
|--|--|
| In a typical WEEK, on how many days did you walk for at least 10 minutes at a time? (Include walking that you do at work, travelling to and from work, and for sport or leisure)                       | Number of days, "Do not know", "Unable to walk", or "Prefer not to answer" |
| How many minutes did you usually spend walking on a typical DAY?   | Quantity of minutes, "Do not know", or "Prefer not to answer"              |
| In a typical WEEK, on how many days did you do 10 minutes or more of moderate physical activities like carrying light loads, cycling at normal pace? (Do not include walking)                          | Number of days, "Do not know", or "Prefer not to answer"                   |
| How many minutes did you usually spend doing moderate activities on a typical DAY?   | Quantity of minutes, "Do not know", or "Prefer not to answer"              |
| In a typical WEEK, how many days did you do 10 minutes or more of vigorous physical activity? (These are activities that make you sweat or breathe hard such as fast cycling, aerobics, heavy lifting) | Number of days, "Do not know", or "Prefer not to answer"                   |
| How many minutes did you usually spend doing vigorous activities on a typical DAY?   | Quantity of minutes, "Do not know", or "Prefer not to answer"              |

**Supplementary Table 2. Spearman correlation between self-reported physical activity and accelerometer-measured physical activity, according to participant characteristics in UK Biobank men**

|   | N Men (%)     | Correlation | 95% Confidence Interval |
|---|---------------|-------------|-------------------------|
| <b>Total</b>                                | 35,955        | 0.24        | 0.23, 0.25              |
| <b>Age group at recruitment (years)</b>     |               |             |                         |
| <55 years                                   | 13,214 (36.8) | 0.31        | 0.29, 0.32              |
| 55+ years                                   | 22,741 (63.3) | 0.22        | 0.21, 0.23              |
| <b>Socioeconomic status, fifths</b>         |               |             |                         |
| Top fifth                                   | 7,584 (21.1)  | 0.23        | 0.21, 0.25              |
| Bottom fifth                                | 6,800 (18.9)  | 0.26        | 0.23, 0.28              |
| <b>BMI (kg/m<sup>2</sup>)</b>               |               |             |                         |
| <25   | 10,590 (29.5) | 0.27        | 0.25, 0.28              |
| 25-29.9                                     | 17,874 (49.7) | 0.21        | 0.19, 0.22              |
| >30   | 7,491 (20.8)  | 0.22        | 0.20, 0.24              |
| <b>College or university degree</b>         |               |             |                         |
| Yes   | 16,709 (46.5) | 0.25        | 0.24, 0.27              |
| No  | 19,246 (53.5) | 0.24        | 0.22, 0.25              |
| <b>Current employment status</b>            |               |             |                         |
| In paid employment or self-employed         | 22,942 (63.8) | 0.27        | 0.26, 0.28              |
| Retired                                     | 11,361 (31.6) | 0.24        | 0.22, 0.26              |
| Other                                       | 1,652 (4.6)   | 0.30        | 0.26, 0.34              |
| <b>Job involves mainly walking/standing</b> |               |             |                         |
| Never or rarely                             | 9,825 (42.8)  | 0.29        | 0.27, 0.31              |
| Sometimes                                   | 7,534 (32.9)  | 0.24        | 0.22, 0.26              |
| Usually or Always                           | 5,574 (24.3)  | 0.19        | 0.16, 0.21              |
| <b>Job involves heavy manual work</b>       |               |             |                         |
| Never, rarely                               | 16,443 (71.7) | 0.27        | 0.26, 0.29              |
| Sometimes                                   | 4,160 (18.1)  | 0.17        | 0.14, 0.19              |
| Usually or Always                           | 2,335 (10.2)  | 0.12        | 0.08, 0.16              |
| <b>Alcohol intake frequency</b>             |               |             |                         |
| Weekly or more                              | 29,421 (81.8) | 0.23        | 0.22, 0.24              |
| Less than weekly                            | 6,530 (18.2)  | 0.28        | 0.26, 0.30              |
| <b>Smoking status</b>                       |               |             |                         |
| Never                                       | 18,928 (52.6) | 0.26        | 0.24, 0.27              |
| Ever  | 16,964 (47.2) | 0.22        | 0.21, 0.24              |
| <b>Long-standing illness or disability</b>  |               |             |                         |
| No  | 25,129 (69.9) | 0.23        | 0.22, 0.24              |
| Yes   | 10,825 (30.1) | 0.25        | 0.23, 0.27              |

**Supplementary Table 3. Spearman correlation between self-reported physical activity and accelerometer-measured physical activity, according to participant characteristics in UK Biobank women**

|   | <b>N Women (%)</b> | <b>Correlation</b> | <b>95% Confidence Interval</b> |
|---|--------------------|--------------------|--------------------------------|
| <b>Total</b>                                | 42,992             | 0.22               | 0.21, 0.23                     |
| <b>Age group at recruitment (years)</b>     |                    |                    |                                |
| <55 years                                   | 18,973 (44.1)      | 0.26               | 0.25, 0.28                     |
| 55+ years                                   | 24,019 (55.9)      | 0.20               | 0.19, 0.22                     |
| <b>Socioeconomic status, fifths</b>         |                    |                    |                                |
| Top fifth                                   | 8,401 (19.5)       | 0.22               | 0.30, 0.24                     |
| Bottom fifth                                | 8,744 (20.3)       | 0.22               | 0.30, 0.24                     |
| <b>BMI (kg/m<sup>2</sup>)</b>               |                    |                    |                                |
| <25   | 20,255 (47.1)      | 0.21               | 0.20, 0.23                     |
| 25-29.9                                     | 15,146 (35.2)      | 0.18               | 0.17, 0.20                     |
| >30   | 7,591 (17.7)       | 0.15               | 0.13, 0.17                     |
| <b>College or university degree</b>         |                    |                    |                                |
| Yes   | 19,214 (44.7)      | 0.22               | 0.21, 0.24                     |
| No  | 23,778 (55.3)      | 0.22               | 0.20, 0.23                     |
| <b>Current employment status</b>            |                    |                    |                                |
| In paid employment or self-employed         | 26,693 (62.1)      | 0.24               | 0.23, 0.25                     |
| Retired                                     | 12,710 (29.6)      | 0.22               | 0.20, 0.24                     |
| Other                                       | 3,589 (8.4)        | 0.30               | 0.27, 0.33                     |
| <b>Job involves mainly walking/standing</b> |                    |                    |                                |
| Never or rarely                             | 12,191 (45.7)      | 0.25               | 0.23, 0.27                     |
| Sometimes                                   | 7,839 (29.4)       | 0.21               | 0.19, 0.23                     |
| Usually or Always                           | 6,648 (24.9)       | 0.18               | 0.16, 0.20                     |
| <b>Job involves heavy manual work</b>       |                    |                    |                                |
| Never, rarely                               | 20,762 (77.8)      | 0.24               | 0.22, 0.25                     |
| Sometimes                                   | 4,353 (16.3)       | 0.17               | 0.14, 0.20                     |
| Usually or Always                           | 1,567 (5.9)        | 0.13               | 0.08, 0.18                     |
| <b>Alcohol intake frequency</b>             |                    |                    |                                |
| Weekly or more                              | 29,829 (69.4)      | 0.22               | 0.21, 0.23                     |
| Less than weekly                            | 13,152 (30.6)      | 0.21               | 0.20, 0.23                     |
| <b>Smoking status</b>                       |                    |                    |                                |
| Never                                       | 25,998 (60.5)      | 0.21               | 0.20, 0.22                     |
| Ever  | 16,936 (39.4)      | 0.23               | 0.22, 0.25                     |
| <b>Long-standing illness or disability</b>  |                    |                    |                                |
| No  | 32,307 (75.2)      | 0.21               | 0.20, 0.22                     |
| Yes   | 10,685 (24.9)      | 0.23               | 0.21, 0.24                     |

Supplementary Table 4. Association of self-reported and accelerometer-measured physical activity with measures of adiposity

|                             | N     | BMI<br>(kg/m <sup>2</sup> ) | 95% CI       | Body fat<br>percent | 95% CI       | Waist circumference<br>(cm) | 95% CI         |
|-----------------------------|-------|-----------------------------|--------------|---------------------|--------------|-----------------------------|----------------|
| <b>Men</b>                  |       |                             |              |                     |              |                             |                |
| <b>Questionnaire</b>        |       |                             |              |                     |              |                             |                |
| Bottom tenth (least active) | 3,643 | 0.00 (reference)            |              | 0.00 (reference)    |              | 0.00 (reference)            |                |
| 2nd tenth                   | 3,742 | -0.69                       | -0.87, -0.52 | -0.99               | -1.23, -0.74 | -1.97                       | -2.45, -1.50   |
| 3rd tenth                   | 3,410 | -0.91                       | -1.09, -0.73 | -1.42               | -1.68, -1.17 | -2.89                       | -3.38, -2.41   |
| 4th tenth                   | 3,677 | -1.22                       | -1.40, -1.05 | -1.97               | -2.22, -1.72 | -3.81                       | -4.29, -3.34   |
| 5th tenth                   | 3,522 | -1.32                       | -1.50, -1.14 | -2.14               | -2.39, -1.88 | -4.47                       | -4.95, -3.99   |
| 6th tenth                   | 3,584 | -1.45                       | -1.63, -1.27 | -2.50               | -2.75, -2.24 | -4.79                       | -5.27, -4.31   |
| 7th tenth                   | 3,596 | -1.59                       | -1.76, -1.41 | -2.88               | -3.13, -2.63 | -5.41                       | -5.89, -4.93   |
| 8th tenth                   | 3,591 | -1.63                       | -1.81, -1.45 | -3.09               | -3.34, -2.83 | -5.92                       | -6.40, -5.44   |
| 9th tenth                   | 3,595 | -1.71                       | -1.89, -1.53 | -3.21               | -3.46, -2.95 | -6.33                       | -6.81, -5.85   |
| Top tenth (most active)     | 3,595 | -1.77                       | -1.95, -1.59 | -3.56               | -3.81, -3.31 | -6.42                       | -6.90, -5.93   |
| <b>Accelerometer</b>        |       |                             |              |                     |              |                             |                |
| Bottom tenth (least active) | 3,598 | 0.00 (reference)            |              | 0.00 (reference)    |              | 0.00 (reference)            |                |
| 2nd tenth                   | 3,604 | -0.77                       | -0.95, -0.60 | -0.99               | -1.24, -0.75 | -2.23                       | -2.70, -1.76   |
| 3rd tenth                   | 3,592 | -1.33                       | -1.50, -1.15 | -1.83               | -2.07, -1.58 | -3.69                       | -4.16, -3.22   |
| 4th tenth                   | 3,610 | -1.60                       | -1.77, -1.42 | -2.20               | -2.45, -1.95 | -4.59                       | -5.06, -4.12   |
| 5th tenth                   | 3,597 | -1.88                       | -2.06, -1.71 | -2.69               | -2.94, -2.44 | -5.43                       | -5.90, -4.96   |
| 6th tenth                   | 3,585 | -2.07                       | -2.24, -1.89 | -3.04               | -3.28, -2.79 | -6.00                       | -6.47, -5.53   |
| 7th tenth                   | 3,589 | -2.32                       | -2.49, -2.14 | -3.52               | -3.77, -3.27 | -7.01                       | -7.49, -6.54   |
| 8th tenth                   | 3,594 | -2.57                       | -2.75, -2.39 | -3.84               | -4.09, -3.59 | -7.69                       | -8.17, -7.22   |
| 9th tenth                   | 3,591 | -3.02                       | -3.20, -2.84 | -4.75               | -5.00, -4.50 | -9.01                       | -9.48, -8.53   |
| Top tenth (most active)     | 3,595 | -3.61                       | -3.79, -3.43 | -5.98               | -6.24, -5.73 | -11.23                      | -11.72, -10.75 |
|                             |       |                             |              |                     |              |                             |                |
|                             |       |                             |              |                     |              |                             |                |



| <b>Women</b>                |       |                  |              |                  |              |                  |                |
|-----------------------------|-------|------------------|--------------|------------------|--------------|------------------|----------------|
| <b>Questionnaire</b>        |       |                  |              |                  |              |                  |                |
| Bottom tenth (least active) | 4,433 | 0.00 (reference) |              | 0.00 (reference) |              | 0.00 (reference) |                |
| 2nd tenth                   | 4,187 | -0.81            | -1.00, -0.61 | -1.05            | -1.33, -0.78 | -1.77            | -2.25, -1.29   |
| 3rd tenth                   | 4,278 | -1.37            | -1.57, -1.18 | -1.89            | -2.16, -1.61 | -3.33            | -3.81, -2.86   |
| 4th tenth                   | 4,318 | -1.44            | -1.64, -1.25 | -2.16            | -2.43, -1.88 | -3.74            | -4.22, -3.27   |
| 5th tenth                   | 4,296 | -1.60            | -1.79, -1.40 | -2.44            | -2.72, -2.17 | -3.92            | -4.39, -3.44   |
| 6th tenth                   | 4,308 | -1.86            | -2.05, -1.66 | -2.89            | -3.16, -2.61 | -4.71            | -5.18, -4.23   |
| 7th tenth                   | 4,276 | -1.98            | -2.18, -1.79 | -3.18            | -3.45, -2.90 | -5.02            | -5.50, -4.55   |
| 8th tenth                   | 4,300 | -2.20            | -2.39, -2.00 | -3.57            | -3.85, -3.30 | -5.73            | -6.20, -5.25   |
| 9th tenth                   | 4,305 | -2.28            | -2.48, -2.09 | -3.86            | -4.14, -3.59 | -5.91            | -6.39, -5.44   |
| Top tenth (most active)     | 4,291 | -2.51            | -2.70, -2.31 | -4.25            | -4.52, -3.97 | -6.39            | -6.87, -5.91   |
| <b>Accelerometer</b>        |       |                  |              |                  |              |                  |                |
| Bottom tenth (least active) | 4,314 | 0.00 (reference) |              | 0.00 (reference) |              | 0.00 (reference) |                |
| 2nd tenth                   | 4,292 | -1.14            | -1.33, -0.95 | -1.43            | -1.70, -1.16 | -3.02            | -3.49, -2.56   |
| 3rd tenth                   | 4,293 | -1.84            | -2.03, -1.65 | -2.35            | -2.62, -2.09 | -4.42            | -4.89, -3.95   |
| 4th tenth                   | 4,307 | -2.31            | -2.50, -2.12 | -2.90            | -3.17, -2.63 | -5.43            | -5.90, -4.97   |
| 5th tenth                   | 4,312 | -2.60            | -2.79, -2.41 | -3.52            | -3.79, -3.25 | -6.27            | -6.74, -5.80   |
| 6th tenth                   | 4,286 | -2.92            | -3.11, -2.72 | -4.05            | -4.32, -3.79 | -7.18            | -7.65, -6.71   |
| 7th tenth                   | 4,292 | -3.22            | -3.42, -3.04 | -4.63            | -4.90, -4.36 | -7.88            | -8.35, -7.41   |
| 8th tenth                   | 4,301 | -3.60            | -3.80, -3.41 | -5.34            | -5.61, -5.07 | -8.80            | -9.27, -8.33   |
| 9th tenth                   | 4,305 | -4.17            | -4.36, -3.98 | -6.37            | -6.64, -6.10 | -10.12           | -10.59, -9.64  |
| Top tenth (most active)     | 4,290 | -4.80            | -4.99, -4.60 | -8.06            | -8.33, -7.78 | -11.92           | -12.39, -11.44 |

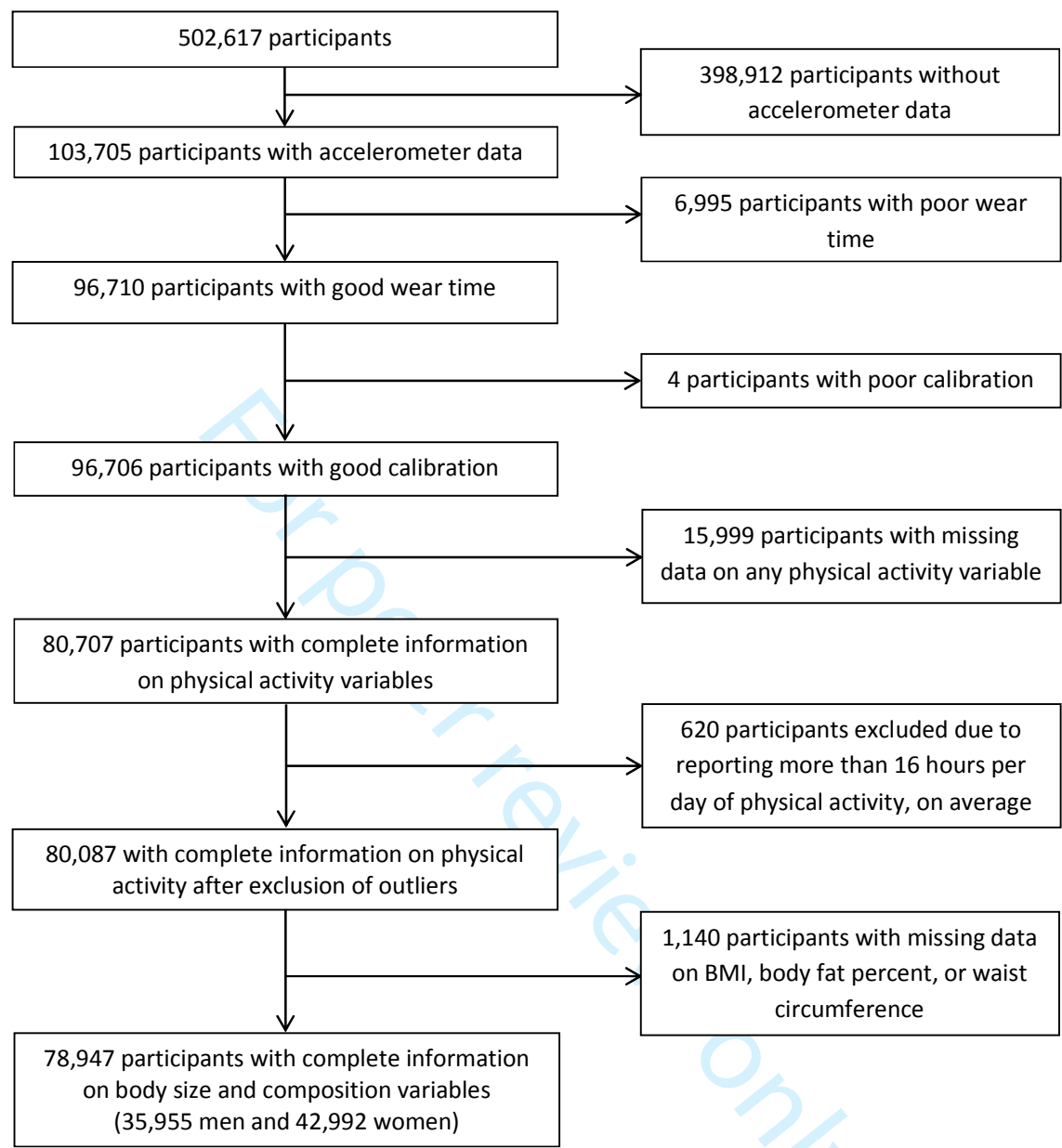
Analyses are adjusted for age, socioeconomic status, alcohol intake, smoking status, educational qualifications, and employment status. Analyses are further adjusted for parity and hormone replacement therapy use in women.

**Supplementary Table 5. Association of accelerometer-measured physical activity with body fat percent, measured by bioelectrical impedance and dual energy X-ray absorptiometry (DXA) in UK Biobank**

| Accelerometer-measured physical activity | N   | Mean body fat percent | 95% CI     | Coefficient            | 95% CI       |
|--|-----|-----------------------|------------|------------------------|--------------|
| <b>Men</b>                               |     |                       |            |                        |              |
| <b>Measured by impedance</b>             |     |                       |            |                        |              |
| Bottom fifth (least active)              | 237 | 27.4                  | 26.7, 28.0 | 0.00 (reference group) |              |
| 2nd fifth                                | 231 | 26.0                  | 25.3, 26.6 | -1.29                  | -2.21, -0.38 |
| 3rd fifth                                | 229 | 24.7                  | 24.0, 25.3 | -2.63                  | -3.55, -1.71 |
| 4th fifth                                | 253 | 23.8                  | 23.1, 24.4 | -3.46                  | -4.36, -2.56 |
| Top fifth (most active)                  | 235 | 21.8                  | 21.1, 22.4 | -5.51                  | -6.45, -4.58 |
| <b>Men</b>                               |     |                       |            |                        |              |
| <b>Measured by DXA</b>                   |     |                       |            |                        |              |
| Bottom fifth (least active)              | 237 | 34.1                  | 33.3, 34.8 | 0.00 (reference group) |              |
| 2nd fifth                                | 231 | 31.6                  | 30.9, 32.4 | -2.38                  | -3.45, -1.31 |
| 3rd fifth                                | 229 | 30.0                  | 29.2, 30.7 | -4.12                  | -5.20, -3.05 |
| 4th fifth                                | 253 | 28.7                  | 28.0, 29.4 | -5.48                  | -6.54, -4.42 |
| Top fifth (most active)                  | 235 | 26.1                  | 25.4, 26.9 | -8.18                  | -9.27, -7.08 |
| <b>Women</b>                             |     |                       |            |                        |              |
| <b>Measured by impedance</b>             |     |                       |            |                        |              |
| Bottom fifth (least active)              | 270 | 38.4                  | 37.6, 39.1 | 0.00 (reference group) |              |
| 2nd fifth                                | 244 | 36.6                  | 35.9, 37.4 | -1.46                  | -2.55, -0.37 |
| 3rd fifth                                | 265 | 36.1                  | 35.4, 36.9 | -1.93                  | -3.01, -0.85 |
| 4th fifth                                | 228 | 34.5                  | 33.7, 35.3 | -3.43                  | -4.55, -2.31 |
| Top fifth (most active)                  | 265 | 30.8                  | 30.1, 31.6 | -6.97                  | -8.07, -5.87 |
| <b>Women</b>                             |     |                       |            |                        |              |
| <b>Measured by DXA</b>                   |     |                       |            |                        |              |
| Bottom fifth (least active)              | 270 | 42.5                  | 41.7, 43.3 | 0.00 (reference group) |              |
| 2nd fifth                                | 244 | 40.4                  | 39.6, 41.2 | -1.87                  | -3.04, -0.71 |
| 3rd fifth                                | 265 | 39.8                  | 39.0, 40.6 | -2.55                  | -3.70, -1.40 |
| 4th fifth                                | 228 | 37.1                  | 36.2, 37.9 | -4.98                  | -6.17, -3.78 |
| Top fifth (most active)                  | 265 | 33.3                  | 32.5, 34.1 | -8.83                  | -10.0, -7.65 |

Analyses are adjusted for age, socioeconomic status, alcohol intake, smoking status, educational qualifications, and employment status. Analyses are further adjusted for parity and hormone replacement therapy use in women.

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STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   |
|------------------------------|---------|--|
| <b>Title and abstract</b>    | 1       | <input checked="" type="checkbox"/> (a) Indicate the study's design with a commonly used term in the title or the abstract   |
|                              |         | <input checked="" type="checkbox"/> (b) Provide in the abstract an informative and balanced summary of what was done and what was found  |
| <b>Introduction</b>          |         |  |
| Background/rationale         | 2       | <input checked="" type="checkbox"/> Explain the scientific background and rationale for the investigation being reported   |
| Objectives                   | 3       | <input checked="" type="checkbox"/> State specific objectives, including any prespecified hypotheses   |
| <b>Methods</b>               |         |  |
| Study design                 | 4       | <input checked="" type="checkbox"/> Present key elements of study design early in the paper  |
| Setting                      | 5       | <input checked="" type="checkbox"/> Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  |
| Participants                 | 6       | <input checked="" type="checkbox"/> (a) Give the eligibility criteria, and the sources and methods of selection of participants  |
| Variables                    | 7       | <input checked="" type="checkbox"/> Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable   |
| Data sources/<br>measurement | 8*      | <input checked="" type="checkbox"/> 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                         |
| Bias                         | 9       | <input checked="" type="checkbox"/> Describe any efforts to address potential sources of bias  |
| Study size                   | 10      | <input checked="" type="checkbox"/> Explain how the study size was arrived at  |
| Quantitative variables       | 11      | <input checked="" type="checkbox"/> Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why   |
| Statistical methods          | 12      | <input checked="" type="checkbox"/> (a) Describe all statistical methods, including those used to control for confounding  |
|                              |         | <input checked="" type="checkbox"/> (b) Describe any methods used to examine subgroups and interactions  |
|                              |         | <input checked="" type="checkbox"/> (c) Explain how missing data were addressed  |
|                              |         | N/A (d) If applicable, describe analytical methods taking account of sampling strategy   |
|                              |         | <input checked="" type="checkbox"/> (e) Describe any sensitivity analyses  |
| <b>Results</b>               |         |  |
| Participants                 | 13*     | <input checked="" type="checkbox"/> (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            |
|                              |         | <input checked="" type="checkbox"/> (b) Give reasons for non-participation at each stage   |
|                              |         | <input checked="" type="checkbox"/> (c) Consider use of a flow diagram   |
| Descriptive data             | 14*     | <input checked="" type="checkbox"/> (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders   |
|                              |         | <input checked="" type="checkbox"/> (b) Indicate number of participants with missing data for each variable of interest  |
| Outcome data                 | 15*     | <input checked="" type="checkbox"/> Report numbers of outcome events or summary measures   |
| Main results                 | 16      | <input checked="" type="checkbox"/> (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 |
|                              |         | <input checked="" type="checkbox"/> (b) Report category boundaries when continuous variables were categorized  |

N/A (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

|                          |    |  |
|--------------------------|----|--|
| Other analyses           | 17 | <input checked="" type="checkbox"/> Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   |
| <b>Discussion</b>        |    |  |
| Key results              | 18 | <input checked="" type="checkbox"/> Summarise key results with reference to study objectives   |
| Limitations              | 19 | <input checked="" type="checkbox"/> Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 |
| Interpretation           | 20 | <input checked="" type="checkbox"/> Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence |
| Generalisability         | 21 | <input checked="" type="checkbox"/> Discuss the generalisability (external validity) of the study results  |
| <b>Other information</b> |    |  |
| Funding                  | 22 | <input checked="" type="checkbox"/> 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              |

\*Give information separately for exposed and unexposed groups.

**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](http://www.strobe-statement.org).

# BMJ Open

## Accelerometer compared with questionnaire measures of physical activity in relation to body size and composition: a large cross-sectional analysis of UK Biobank

|                                 |   |
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| Secondary Subject Heading:      | Public health   |
| Keywords:                       | EPIDEMIOLOGY, adiposity, physical activity, accelerometer, activity monitor   |
|                                 |   |

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Manuscripts

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3 **Accelerometer compared with questionnaire measures of physical activity in relation to**  
4 **body size and composition: a large cross-sectional analysis of UK Biobank**  
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42 Abbreviations: body mass index (BMI), confidence interval (CI), dual-energy X-ray  
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44 absorptiometry (DXA), International Physical Activity Questionnaire (IPAQ), metabolic  
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46 equivalents (METs), standard deviation (SD)  
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## Abstract

**Objectives:** Previous studies of the association between physical activity and adiposity are largely based on physical activity and body mass index (BMI) from questionnaires, which are prone to inaccurate and biased reporting. We assessed the associations of accelerometer-measured compared to questionnaire-measured physical activity with BMI, waist circumference and body fat percent measured by bioelectrical impedance and dual-energy X-ray absorptiometry (DXA).

**Design:** Cross-sectional analysis of UK Biobank participants

**Setting:** UK Biobank assessment centers

**Participants:** 78,947 UK Biobank participants (35,955 men and 42,992 women) aged 40-70 at recruitment, who had physical activity measured by both questionnaire and accelerometer.

**Main outcome measures:** BMI, waist circumference and body fat percent measured by bioelectrical impedance

**Results:** Correlation between accelerometer and questionnaire measures of physical activity, recorded approximately 5.5 years apart, was low overall and even lower in participants with higher BMI and in older participants. Greater physical activity was associated with lower adiposity. Women in the top tenth of accelerometer-measured physical activity had a 4.8 (95% CI: 4.6, 5.0) kg/m<sup>2</sup> lower BMI, 8.1% (95% CI: 7.8, 8.3) lower body fat percent, and 11.9 (95% CI 11.4, 12.4) cm lower waist circumference. Women in the top tenth of questionnaire-measured physical activity had a 2.5 (95% CI: 2.3, 2.7) kg/m<sup>2</sup> lower BMI, 4.3% (95% CI: 4.0, 4.5) lower body fat percent, and 6.4 (95% CI: 5.9, 6.9) cm lower waist circumference, compared to women in the bottom tenths. The patterns were similar in men and also similar with body fat percent measured by DXA compared to impedance.



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3 **Conclusion:** Our findings of approximately twofold stronger associations between physical  
4 activity and adiposity with objectively-measured compared to self-reported physical activity  
5 demonstrate substantial measurement error in self-reported physical activity, especially  
6 among participants with higher BMI and among older participants, and further emphasizes  
7 the need to incorporate objective measures in future studies.  
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17 **Strengths and limitations of this study:**  
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21 • This study utilizes data on physical activity objectively measured by accelerometer  
22 rather than only self-reported data from questionnaires, which are prone to inaccurate  
23 and potentially biased reporting.  
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27 • This study is by far the largest study to compare associations between physical  
28 activity objectively measured by accelerometer and self-reported physical activity in  
29 relation to various measures of adiposity, including body fat percent assessed by  
30 bioelectrical impedance and dual energy x-ray absorptiometry.  
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36 • Due to the cross-sectional nature of this study, we cannot assess to what extent  
37 physical activity is causally related to adiposity.  
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## INTRODUCTION

The prevalence of overweight and obesity is high worldwide and is associated with increased risk of various conditions including heart disease, stroke, hypertension, diabetes, and some cancers (1, 2). Although physical activity is generally accepted to be important for prevention of weight gain, achievement of modest weight loss, and prevention of weight regain after weight loss (3), randomized controlled trials have shown inconsistent results, perhaps partly due to limited duration of interventions and difficulty in long-term adherence to exercise regimens (4), and previous large-scale observational studies are mostly based on self-reported physical activity from questionnaires, which are prone to both inaccurate reporting and reporting bias (5).

Prior studies have demonstrated low to moderate correlation between self-reported and objective accelerometer measures of physical activity (6, 7). Self-reported and accelerometer-measured physical activity capture different aspects of physical activity with limitations unique to each (7). However, research methods utilizing more objective measures of physical activity, along with more detailed measures of body fat, are needed to reduce measurement error and more accurately characterize the association between physical activity and adiposity.

We examined the association between physical activity and adiposity, with accelerometer-measured compared to self-reported physical activity in nearly 80,000 participants. These associations were assessed using various measures of adiposity, including BMI, waist circumference, and body fat percent measured by both bioelectrical impedance and dual-energy X-ray absorptiometry (DXA). We also explored how the associations vary by age.

## METHODS

### Data source

Data were obtained from UK Biobank. Details of UK Biobank design, rationale, and survey methods have been described elsewhere (8). Information on data available and access procedures are described on the study website (<http://www.ukbiobank.ac.uk/>). UK Biobank has approval from the National Information Governance Board for Health & Social Care in England and Wales, the North West Multi-centre Research Ethics Committee, and the Community Health Index Advisory Group in Scotland. Written informed consent was provided by all participants.

### Study participants

The complete UK Biobank dataset includes 502,617 UK adults (229,164 men and 273,453 women) between 40 to 70 years of age at recruitment during 2006 to 2010. During the baseline assessment center visit, participants completed a touchscreen questionnaire which included questions on socio-demographics, lifestyle, health and medical history, and sex-specific factors. The present study was restricted to participants with available accelerometer data (n=103,705). Participants were excluded if they did not have at least 72 hours of data and also data in each one-hour period of the 24-hour cycle across multiple days (n=6,995). Participants were also excluded if they had insufficient data for calibration (n=4). Participants who had missing data on any of the physical activity variables used in our analyses were excluded (n=15,999). Participants who reported physical activity greater than an average of 16 hours per day (n=620) were also excluded as recommended by the International Physical Activity Questionnaire (IPAQ) scoring guidelines, which can be accessed at <file:///H:/Downloads/GuidelinesforDataProcessingandAnalysisoftheInternationalPhysicalActivityQuestionnaireIPAQShortandLongForms.pdf>. Finally, participants with missing data on

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3 BMI (n=146), body fat percent (n=988), and waist circumference (n=6) were excluded. The  
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5 analyses included 35,955 men and 42,992 women (**Supplementary Figure 1**).

#### 6 7 8 Self-reported physical activity

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10 Physical activity questions from the baseline questionnaire captured the frequency and  
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12 duration of three intensities of activity (walking, moderate, and vigorous). Participants were  
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14 asked how many days per week they typically engaged in each category of activity. For each  
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16 category in which an answer of one or more days was given, the participant was subsequently  
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18 asked the number of minutes on average spent on the activity per day. Questions were  
19  
20 asked the number of minutes on average spent on the activity per day. Questions were  
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22 adapted from the IPAQ, a validated survey instrument (9), and are listed in **Supplementary**  
23  
24 **Table 1**. Metabolic equivalents (METs) were used to quantify physical activity; 1 MET is  
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26 expended by sitting quietly for 1 hour, and the MET value reflects the ratio of energy  
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28 expended per kilogram of body weight per hour to that expended when sitting quietly (10).  
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30 The number of minutes per day engaged in each level of activity was multiplied by the  
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32 respective MET score for the corresponding level of activity (3.3 for walking, 4.0 for  
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34 moderate physical activity, and 8.0 for vigorous physical activity) (11). MET minutes per day  
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36 were converted to MET hours per week. The total amount of METs was calculated by  
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38 summing total METs from the walking, moderate, and vigorous activity levels. Following  
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40 IPAQ scoring guidelines, physical activity of less than 10 minutes per day for any category  
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42 was recoded to 0.  
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#### 45 46 Accelerometer-measured physical activity

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49 A total of 236,519 participants, all of whom had provided a valid email address, were  
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51 invited to participate in a seven day accelerometer study between February 2013 and  
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53 December 2015 (on average, approximately 5.5 years after recruitment when baseline  
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55 physical activity was self-reported). Starting in June 2013, participants were sent wrist-worn  
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3 triaxial accelerometers (Axivity AX3, Newcastle upon Tyne, UK) that were programmed to  
4 capture three-dimensional acceleration data at 100 Hz with a dynamic range of  $\pm 8$  g.

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6 Participants were also given instructions to wear the accelerometer on their dominant wrist  
7 continuously for seven days and then to send the device to the coordinating center using the  
8 provided prepaid envelope. Further details on data collection, processing, and analysis can be  
9 found elsewhere (12). We used the “overall acceleration average” variable (data field 90012)  
10 in the present analyses.  
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### 18 Anthropometry and body composition

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21 At the UK Biobank baseline interview, trained staff measured standing height using the  
22 Seca 202 device (Seca, Hamburg, Germany). BMI was calculated by dividing weight (kg) by  
23 the square of standing height ( $m^2$ ). The Wessex non-stretchable sprung tape measure  
24 (Wessex, United Kingdom) was used to measure waist circumference at the level of the  
25 umbilicus. The Tanita BC-418MA body composition analyzer (Tanita, Tokyo, Japan) was  
26 used to measure body fat percent using bioelectrical impedance. DXA was used to measure  
27 fat percent on a subset of 2,457 participants included in the present study, beginning in 2014  
28 using the GE-Lunar iDXA (GE Healthcare, Chicago, USA).  
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### 40 Statistical analyses

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42 Baseline characteristics were summarized by physical activity (least active fifth, most  
43 active fifth, and overall) separately for men and women. Since self-reported physical activity  
44 was not normally distributed, Spearman’s correlation coefficients were used to measure the  
45 strength of correlations between self-reported and accelerometer-measured physical activity  
46 in the overall population and in subgroups based on sociodemographic characteristics.  
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3 Self-reported and accelerometer-measured physical activity were categorized into tenths  
4 and the median value within each category of physical activity is shown in the figures. The  
5 associations of physical activity and adiposity measures were examined using multivariable  
6 linear regression, separately in men and women. Analyses comparing the association of  
7 accelerometer-measured physical activity with body fat percent, measured by bioelectrical  
8 impedance and DXA were restricted to participants with both measures. Likelihood ratio tests  
9 were used to assess whether the associations between physical activity and adiposity were  
10 modified by age (<55 years or 55+ years), separately for self-reported and accelerometer-  
11 measured physical activity.  
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23 Covariates were determined a priori and were 5-year age at recruitment categories,  
24 socioeconomic status as indicated by fifths of Townsend deprivation index (13), educational  
25 qualifications, employment status, smoking status (never, previous, current), and alcohol  
26 intake frequency. Analyses in women were additionally adjusted for parity (nulliparous, 1, 2,  
27 3, 4 or more births) and hormone replacement therapy use (never, previous, current). As a  
28 covariate, educational qualification was grouped into the following categories: vocational  
29 qualifications, national exams at age 16 (O levels, GCSEs, CSEs, or equivalent), optional  
30 national exams at ages 17-18 years (A levels, AS levels, or equivalent), and college or  
31 university degree. Employment status was categorized as paid or self-employed, retired,  
32 looking after home and/or family, unemployed, doing unpaid or voluntary work, unable to  
33 work due to sickness or disability, and student. Alcohol intake was categorized as never,  
34 special occasions only, 1-3 times a month, 1-2 times a week, 3-4 times a week, and daily or  
35 almost daily.  
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51 Missing data were grouped in a separate unknown category for each covariate. There were  
52 less than 1% missing data for all covariates except for educational qualifications (7.4%  
53 missing data). To assess the impact of missing values, a sensitivity analysis restricted to  
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participants with known values for all covariates was conducted. We also conducted sensitivity analyses to assess the impact of excluding participants who reported long-term illness, disability or infirmity, participants who reported fair or poor health rather than excellent or good health, and participants whose jobs usually or always required heavy manual work. Analyses were conducted using STATA, version 15.0 (Stata Corp LP, College Station, TX).

#### Patient and public involvement

This study did not involve patients and the public.

## RESULTS

Characteristics of the study population by least active and most active fifth of accelerometer-measured physical activity are shown in **Table 1**.

**Table 1. Characteristics of the UK Biobank study population, according to fifths of accelerometer-measured physical activity.**

|  | Least active men    | Most active men     | All men           | Least active women  | Most active women   | All women         |
|--|---------------------|---------------------|-------------------|---------------------|---------------------|-------------------|
|  | <20.8 milli-gravity | ≥33.7 milli-gravity |                   | <22.2 milli-gravity | ≥34.6 milli-gravity |                   |
| <b>Number of participants</b>  | 7,202               | 7,186               | 35,955            | 8,606               | 8,595               | 42,992            |
| <b>Age at recruitment (years), mean (SD)</b>                               | 59.7 (7.0)          | 53.4 (7.7)          | 56.7 (7.9)        | 58.0 (7.4)          | 52.6 (7.4)          | 55.3 (7.7)        |
| <b>Lowest fifth of socioeconomic status</b>                                | 1,520 (21.1%)       | 1,351 (18.8%)       | 6,800 (18.9%)     | 1,897 (22.0%)       | 1,699 (19.8%)       | 8,744 (20.3%)     |
| <b>Accelerometer-measured physical activity (milli-gravity), mean (SD)</b> | 17.5 (2.6)          | 40.5 (7.8)          | 27.6 (8.7)        | 18.9 (2.7)          | 40.6 (6.3)          | 28.7 (8.0)        |
| <b>Self-reported physical activity (MET-hours/week), median (IQR)</b>      | 20.7 (9.0, 42.6)    | 44.2 (23.7, 80.9)   | 29.9 (14.2, 58.1) | 21.3 (9.9, 41.7)    | 40.2 (21.8, 73.2)   | 29.3 (14.4, 55.3) |
| <b>Height (cm), mean (SD)</b>  | 176.3 (6.8)         | 176.4 (6.6)         | 176.5 (6.6)       | 163.2 (6.3)         | 163.7 (6.1)         | 163.5 (6.2)       |
| <b>Weight (kg), mean (SD)</b>  | 89.4 (15.4)         | 80.8 (11.4)         | 84.9 (13.5)       | 75.5 (15.6)         | 65.0 (10.3)         | 69.9 (13.2)       |
| <b>BMI (kg/m<sup>2</sup>), mean (SD)</b>                                   | 28.8 (4.6)          | 25.9 (3.3)          | 27.2 (4.0)        | 28.3 (5.7)          | 24.3 (3.7)          | 26.2 (4.8)        |
| <b>Body fat percent (%)<sup>a</sup>, mean (SD)</b>                         | 27.0 (5.6)          | 21.7 (5.4)          | 24.4 (5.7)        | 38.7 (6.6)          | 31.7 (6.4)          | 35.3 (6.8)        |
| <b>Waist circumference (cm), mean (SD)</b>                                 | 100.1 (11.7)        | 90.9 (9.3)          | 95.4 (10.8)       | 87.9 (13.3)         | 77.6 (9.5)          | 82.4 (11.7)       |
| <b>College or university</b>   | 3,018 (41.9%)       | 3,365               | 16,709            | 3,586 (41.7%)       | 4,060               | 19,214            |

|   |               |               |                |               |               |                |
|---|---------------|---------------|----------------|---------------|---------------|----------------|
| <b>degree</b>   |               | (46.8%)       | (46.5%)        |               | (47.2%)       | (44.7%)        |
| <b>Current employment status</b>                        |               |               |                |               |               |                |
| Paid employment/self-employed                           | 3,608 (50.1%) | 5,420 (75.4%) | 22,942 (63.8%) | 4,401 (51.1%) | 6,101 (71.0%) | 26,693 (62.1%) |
| Retired   | 3,107 (43.1%) | 1,451 (20.2%) | 11,361 (31.6%) | 3,517 (40.9%) | 1,591 (18.5%) | 12,710 (29.6%) |
| Other   | 487 (6.8%)    | 315 (4.4%)    | 1,652 (4.6%)   | 688 (8.0%)    | 903 (10.5%)   | 3,589 (8.3%)   |
| <b>Job involves mainly walking/standing<sup>b</sup></b> | 707 (19.6%)   | 1,742 (32.1%) | 5,574 (24.3%)  | 893 (20.3%)   | 1,926 (31.6%) | 6,648 (24.9%)  |
| <b>Job involves heavy manual work<sup>c</sup></b>       | 272 (7.5%)    | 912 (16.8%)   | 2,335 (10.2%)  | 170 (3.9%)    | 576 (9.4%)    | 1,567 (5.9%)   |
| <b>Weekly or more frequent alcohol intake</b>           | 5,545 (77.0%) | 5,989 (83.3%) | 29,421 (81.8%) | 5,295 (61.5%) | 6,292 (73.2%) | 29,829 (69.4%) |
| <b>Ever smoker</b>                                      | 3,801 (52.8%) | 3,126 (43.5%) | 16,964 (47.2%) | 3,583 (41.6%) | 3,212 (37.4%) | 16,936 (39.4%) |
| <b>Long-standing illness or disability</b>              | 3,089 (42.9%) | 1,543 (21.5%) | 10,825 (30.1%) | 3,145 (36.5%) | 1,449 (16.9%) | 1,0685 (24.9%) |

<sup>a</sup> Body fat percent was measured by bioelectrical impedance

<sup>b</sup> Participants who reported their work “usually” or “always” involved walking or standing for most of the time

<sup>c</sup> Participants who reported their work “usually” or “always” involved heavy manual or physical work for most of the time

Mean accelerometer-measured physical activity was 27.6 (standard deviation [SD] 8.7) milli-gravity in men and 28.7 (SD 8.0) milli-gravity in women. The most active participants were on average younger and had lower values for all body size and composition variables. They were more likely to have a college or university degree, be employed rather than retired, have an active job, and consume alcohol at least weekly. The least active participants were more likely to be ever smokers and were also more likely to have a long-standing illness or disability. The correlation between questionnaire and accelerometer-measured physical activity, recorded on average 5.5 years later, was 0.24 (95% confidence interval [CI]: 0.23, 0.25) in men (**Supplementary Table 2**) and 0.22 (95% CI: 0.21, 0.23) in women (**Supplementary Table 3**). The correlations were comparatively higher in participants who were younger and in participants who had lower BMI. The correlations were lower among



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3 participants who reported that their job usually or always involved heavy manual work and/or  
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5 mainly walking or standing.  
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8 The inverse associations between physical activity and all measures of adiposity were  
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10 linear and approximately twofold larger in models that used accelerometer-measured rather  
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12 than self-reported physical activity. Since there was heterogeneity in the associations between  
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14 both self-reported and accelerometer-measured physical activity and adiposity by sex  
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16 ( $P<0.001$ ), separate analyses were performed in men and women. The mean differences in  
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18 BMI and body fat percent were greater in women compared to men. Comparing the top to  
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20 bottom tenth of accelerometer-measured physical activity, the difference in BMI was 4.8  
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22 (95% CI: 4.6, 5.0)  $\text{kg/m}^2$  in women and 3.6 (95% CI: 3.4, 3.8)  $\text{kg/m}^2$  in men (**Figure 1,**  
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24 **Supplementary Table 4**).  
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28 Women in the top tenth of accelerometer-measured physical activity had an 8.1% (95%  
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30 CI: 7.8, 8.3) lower body fat percent while women in the top tenth of self-reported physical  
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32 activity had a 4.3% (95% CI: 4.0, 4.5) lower body fat percent, compared to those in the  
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34 bottom tenth of physical activity. Men in the top tenth of accelerometer-measured physical  
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36 activity had a 6.0% (95% CI: 5.7, 6.2) lower body fat percent while men in the top tenth of  
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38 self-reported physical activity had a 3.6% (95% CI: 3.3, 3.8) lower body fat percent,  
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40 compared to those in the bottom tenth (**Figure 1, Supplementary Table 4**).  
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44 Associations between physical activity and waist circumference were of similar magnitude  
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46 in men and women, with an approximately twofold larger inverse association between waist  
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48 circumference and physical activity when measured by accelerometer rather than  
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50 questionnaire (**Figure 1, Supplementary Table 4**).  
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53 The results of sensitivity analyses excluding participants who had any missing values,  
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55 reported a long-term illness or disability, reported a health rating worse than “good”, or  
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3 whose jobs usually or always required heavy manual work did not materially differ from the  
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5 main findings.  
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8 **Figure 2 and Supplementary Table 5** show the associations between accelerometer-  
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10 measured physical activity and bioelectrical impedance-measured body fat percent at baseline  
11 (2006-2010) compared to body fat percent measured by DXA starting in May 2014. Body fat  
12 percent by impedance at baseline was lower than body fat percent by DXA, measured on  
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14 average seven years later. For both measures, there was a linear dose-response association  
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16 between physical activity and body fat percent in both men and women. The inverse  
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18 associations were stronger when body fat percent was measured by DXA. Compared to the  
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20 least active women, the most active women had an 8.8% (95% CI: 7.7, 10.0) lower DXA-  
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22 measured body fat percent and a 7.0% (95% CI: 5.9, 8.1) lower impedance-measured body  
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24 fat percent (**Figure 2 and Supplementary Table 5**).  
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30 Associations between physical activity and measures of adiposity by age group are shown  
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32 in **Figure 3** for men and **Figure 4** for women. For a given level of accelerometer-measured  
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34 physical activity, the older participants (over age 55) had a slightly lower BMI but a higher  
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36 body fat percent compared to their younger counterparts. For women, there was heterogeneity  
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38 by age in the association between self-reported physical activity and body fat percent  
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40 ( $P=0.03$ ) but there was no heterogeneity by age when physical activity was measured by  
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42 accelerometer ( $P=0.27$ ).  
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## 46 DISCUSSION

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49 In this large cross-sectional study of nearly 80,000 participants, we found that associations  
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51 between physical activity and BMI, body fat percent, and waist circumference were stronger  
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53 when physical activity was measured by accelerometer compared to questionnaire self-  
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55 reports. Body fat percent measured by DXA at follow-up showed a slightly stronger  
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3 association with physical activity compared to body fat percent measured by bioelectrical  
4 impedance at baseline, but the overall pattern of association was similar. The correlation  
5 between accelerometer-measured and self-reported physical activity, recorded 5.5 years apart,  
6 was lower in participants with higher BMI and in older participants.  
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12 There was a consistent dose-response relationship between physical activity and adiposity  
13 across the different measures of adiposity, which are highly correlated (14). Our analyses  
14 based on accelerometer-measured physical activity suggest an approximately linear inverse  
15 association between physical activity and adiposity, with the most active participants having  
16 the lowest BMI, body fat percent, and waist circumference. In contrast, the analyses in the  
17 same participants based on self-reported physical activity suggest a comparatively small  
18 further benefit of physical activity greater than 50 MET-hours a week on adiposity.  
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28 We have previously suggested that the steeper relationship between physical activity and  
29 lower adiposity within the lower range of physical activity could be due to either a  
30 comparatively larger benefit of physical activity for those who are relatively inactive or  
31 measurement error from over-reporting of high physical activity (14). The present analyses  
32 demonstrating an approximately linear dose-response relationship between accelerometer-  
33 measured physical activity and adiposity supports the latter explanation and further suggests  
34 that over-reporting of total physical activity contributed to the low overall correlation  
35 between self-reported and accelerometer-measured physical activity, although the time lag  
36 between these two measurements of physical activity may have also contributed to a low  
37 overall correlation coefficient. Wrist accelerometer-measured physical activity also has  
38 limitations, such as measuring movement of only one part of the body and the inability to  
39 reliably capture activities such as cycling (7), it has the major advantage of eliminating both  
40 inaccurate reporting that leads to random error as well as reporting bias that may vary by  
41 sociodemographic characteristics.  
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3 Measurement error in the self-reported data results in misclassification of individuals by  
4 physical activity status. We used the IPAQ short form data processing rules since the UK  
5 Biobank questionnaire did not comprehensively cover domain-specific activities, but it is still  
6 likely that lower intensity activities were underreported and reported less accurately (15). In  
7 contrast, the accelerometers were worn for 24 hours a day, over 7 days. Therefore, the lower  
8 correlation between self-reported and accelerometer-measured physical activity in older  
9 participants (16) and the heterogeneity by age seen only with the self-reported data may be  
10 explained by the observation that, in older adults, a greater proportion of physical activity is  
11 of lower intensity (17).  
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23 Individuals with higher body fat percent may report moderate and strenuous physical  
24 activity less accurately than leaner individuals, based on comparisons between self-reported  
25 physical activity and energy expenditure estimated from whole-room indirect calorimeter  
26 (18). In agreement with some previous studies, we found that the correlation between  
27 physical activity measured by questionnaire and accelerometer-measured physical activity  
28 was greater for those with lower BMI (7). This suggests that measurement error of self-  
29 reported physical activity may be greater in overweight and obese BMI groups.  
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39 We, like several prior studies, found stronger associations between accelerometer-  
40 measured physical activity and all measures of adiposity in women compared to men (19–  
41 21). This may partly be due to the fact that, in the present study, men were on average  
42 objectively less physically active than women. Differences in fat metabolism may also play a  
43 role, with a greater proportion of energy derived from lipolysis during exercise in women  
44 compared to men (21, 22).  
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52 To our knowledge, the present study is the largest to date comparing accelerometer-  
53 measured and self-reported physical activity in relation to direct measures of body fat,  
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3 although our results are consistent with prior, smaller studies that suggest a stronger  
4 association between adiposity and accelerometer-measured compared to self-reported  
5 physical activity (18, 20, 23–26). This study was population-based and recruited from 22  
6 regions throughout the UK (27). A major strength of this study is the availability of both  
7 accelerometer-measured physical activity and body fat by impedance in nearly 80,000  
8 participants, together with data on body fat assessed by DXA in over 2,400 participants.  
9 Additionally, the accelerometers used in this study were waterproof (12), overcoming a  
10 limitation of prior studies where the devices had to be removed for water-based activities  
11 (21).  
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23 While self-reported physical activity was available at baseline in these data,  
24 accelerometer-measured physical activity was assessed only 3-5 years after end of  
25 recruitment, which raises the question of whether higher adiposity at baseline predicts lower  
26 physical activity levels (28) rather than physical activity determining adiposity. However, our  
27 analysis of accelerometer-measured physical activity in relation to DXA-measured body fat  
28 percent, which was assessed within the same time frame as accelerometer-measured physical  
29 activity, showed similar results to the main analysis based on body fat percent assessed by  
30 impedance at baseline. The accelerometer-measured physical activity variable available in  
31 UK Biobank at the time of these analyses cannot be directly compared to MET hours of self-  
32 reported physical activity. However, Willetts et al. have recently developed physical activity  
33 phenotypes using a machine learning model with reference behaviors provided by data from a  
34 subset of participants who wore a camera along with the accelerometer (29). Once these  
35 variables are made publicly available in UK Biobank, research using these metrics will  
36 facilitate the translation of study results into public health messages.  
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54 Other limitations include the lack of data on total energy intake for the whole cohort.  
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56 Although accelerometer-determined physical activity is positively associated with percent of  
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3 lean muscle mass (30), we did not consider this as a confounder in these analyses since we  
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5 utilized data on direct measures of body fat percent. Since accelerometer-measured time  
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7 spent in sedentary activity was not available, we did not conduct analyses on sedentary  
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9 activity. Due to the cross-sectional nature of this study, we cannot assess to what extent  
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11 physical activity is causally related to adiposity. Highly active individuals may also be more  
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13 likely to maintain appropriate target dietary energy intake, for example. Although the UK  
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15 Biobank cohort is not representative of the general population in the UK, results of  
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17 associations between exposures and health outcomes may be generalizable and would not  
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19 necessarily require the study population to be representative if the biological basis of the  
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21 exposure-disease relationship is shared.  
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25 In conclusion, our findings based on objective accelerometer data indicate a stronger  
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27 relationship between physical activity and adiposity than previously thought. Comparison of  
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29 estimates of physical activity measured by questionnaire and by accelerometer suggest  
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31 substantial measurement error in self-reported physical activity, emphasizing the need to  
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33 incorporate objective measures of physical activity in future studies.  
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48 **Contributors:** WG, TJK, and GKR were responsible for study concept, design of the study,  
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50 interpretation of the data, and manuscript writing. WG had primary responsibility for  
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52 statistical analysis and final content. All authors reviewed and approved the final manuscript.  
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55 **Dating sharing statement:** No additional data are available.  
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## Figure legends

**Figure 1.** Association of self-reported and accelerometer-measured physical activity with adiposity variables in UK Biobank

Association of A) accelerometer-measured and B) self-reported physical activity with BMI

Association of C) accelerometer-measured and D) self-reported physical activity with body fat percent

Association of E) accelerometer-measured and F) self-reported physical activity with waist circumference

Physical activity was grouped into tenths, separately in men and women.

Adjusted geometric means (from linear regression models) for BMI, body fat percent, and waist circumference are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by squares for men and triangles for women.

These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use.

The figure shows point estimates and 95% confidence intervals.

Abbreviations: BMI, body mass index; MET, metabolic equivalent

**Figure 2.** Association of accelerometer-measured physical activity with body fat percent measured by impedance and DXA in UK Biobank A) men (n=1,185) and B) women (n=1,272)

Physical activity was grouped into fifths, separately in men and women.

Adjusted geometric means (from linear regression models) for body fat percent are plotted against the median value within each fifth of accelerometer-measured physical activity.

Adjusted geometric means are represented by diamonds for body fat percent measured by impedance and circles for body fat percent measured by DXA.

These analyses are restricted to participants with measures of body fat percent by both impedance and DXA. Analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use.

The figure shows point estimates and 95% confidence intervals.

Abbreviations: DXA, dual-energy X-ray absorptiometry

**Figure 3.** Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank men

Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI.

Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent.

Physical activity was grouped into tenths.

Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-

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3 measured physical activity. Adjusted geometric means are represented by diamonds for those  
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5 under age 55 and squares for those ages 55 or older.  
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10 status, and are adjusted for educational qualifications, employment status, smoking status,  
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12 and alcohol intake frequency.  
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15 The figure shows point estimates and 95% confidence intervals.  
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18 Abbreviations: BMI, body mass index; MET, metabolic equivalent  
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24 **Figure 4.** Association of self-reported and accelerometer-measured physical activity with  
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26 adiposity variables by age group in UK Biobank women  
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29 Association of physical activity measured by A) accelerometer and B) self-reported  
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31 questionnaire with BMI.  
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34 Association of physical activity measured by C) accelerometer and D) self-reported  
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36 questionnaire with body fat percent.  
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11 **Supplementary Figure 1.** Flowchart illustrating the application of exclusion criteria for the  
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13 current study in UK Biobank  
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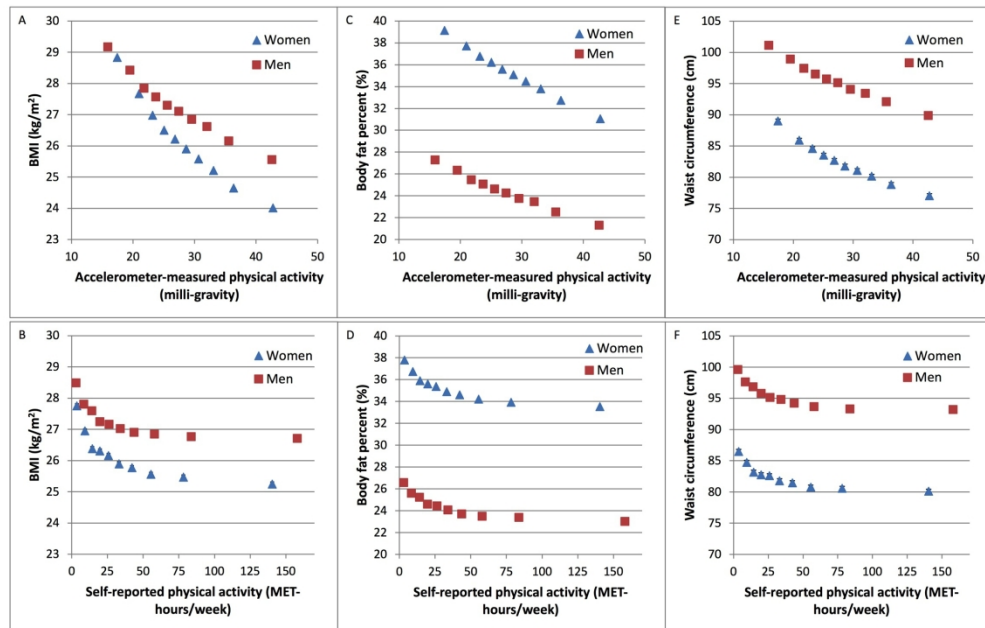


Figure 1. Association of self-reported and accelerometer-measured physical activity with adiposity variables in UK Biobank. Association of A) accelerometer-measured and B) self-reported physical activity with BMI. Association of C) accelerometer-measured and D) self-reported physical activity with body fat percent. Association of E) accelerometer-measured and F) self-reported physical activity with waist circumference. Physical activity was grouped into tenths, separately in men and women. Adjusted geometric means (from linear regression models) for BMI, body fat percent, and waist circumference are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by squares for men and triangles for women. These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use. The figure shows point estimates and 95% confidence intervals. Abbreviations: BMI, body mass index; MET, metabolic equivalent

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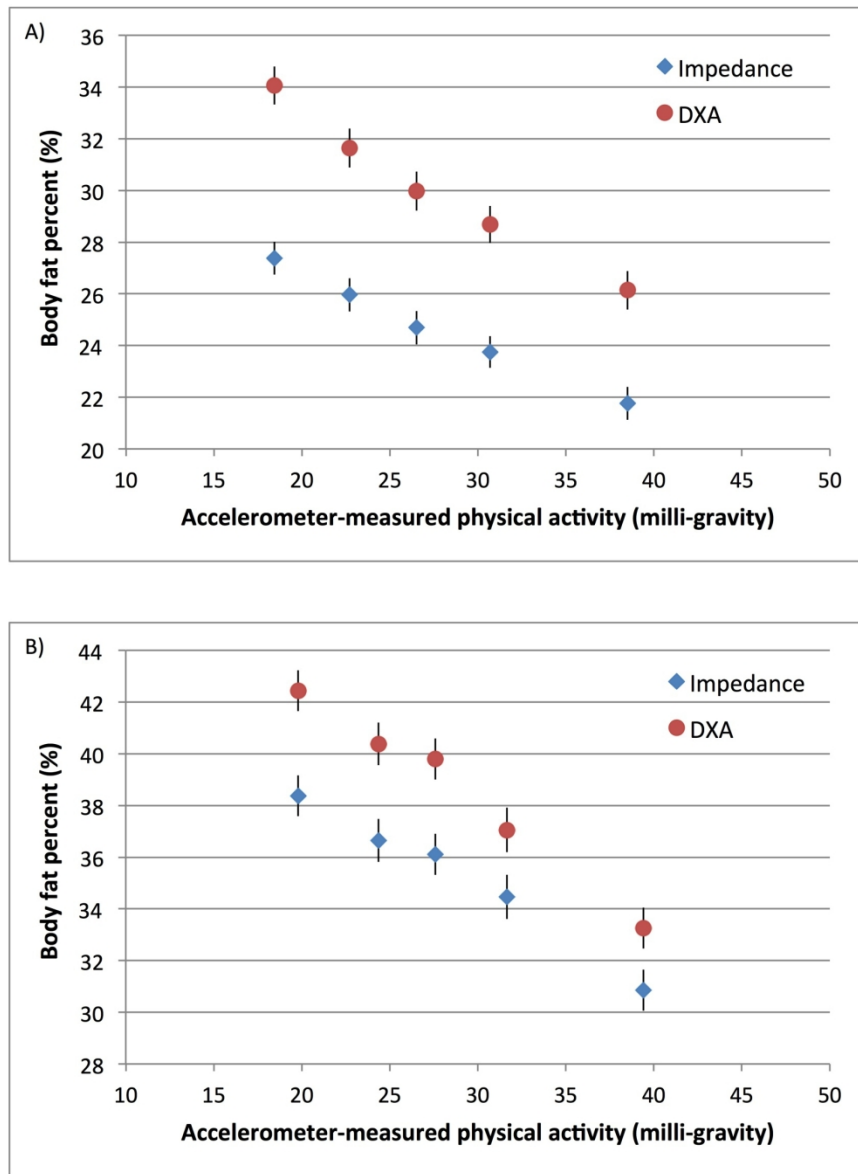


Figure 2. Association of accelerometer-measured physical activity with body fat percent measured by impedance and DXA in UK Biobank A) men (n=1,185) and B) women (n=1,272) Physical activity was grouped into fifths, separately in men and women. Adjusted geometric means (from linear regression models) for body fat percent are plotted against the median value within each fifth of accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for body fat percent measured by impedance and circles for body fat percent measured by DXA. These analyses are restricted to participants with measures of body fat percent by both impedance and DXA. Analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use. The figure shows point estimates and 95% confidence intervals. Abbreviations: DXA, dual-energy X-ray absorptiometry

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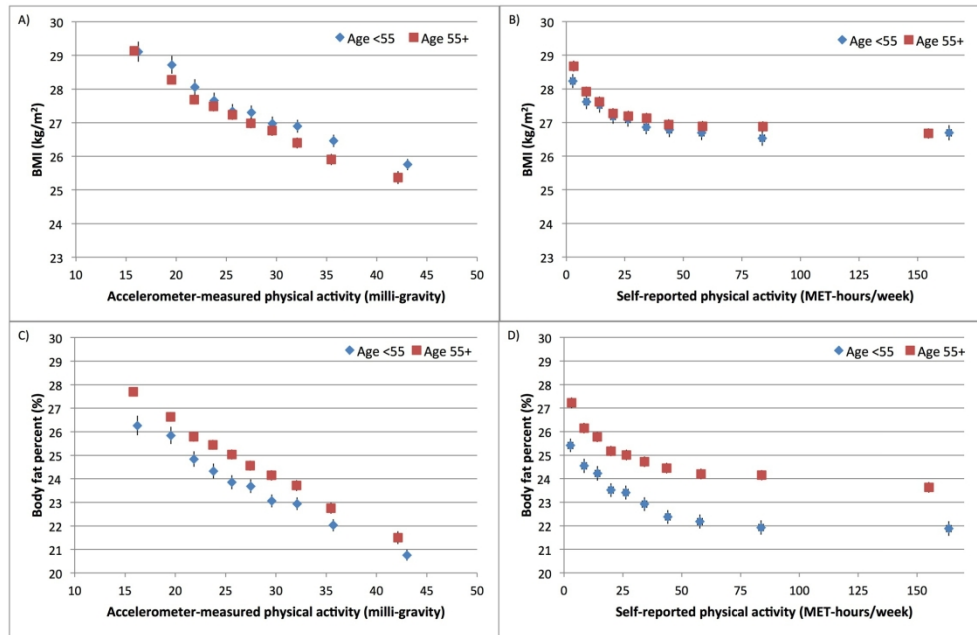


Figure 3. Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank men. Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI. Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent. Physical activity was grouped into tenths. Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for those under age 55 and squares for those ages 55 or older. These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. The figure shows point estimates and 95% confidence intervals. Abbreviations: BMI, body mass index; MET, metabolic equivalent

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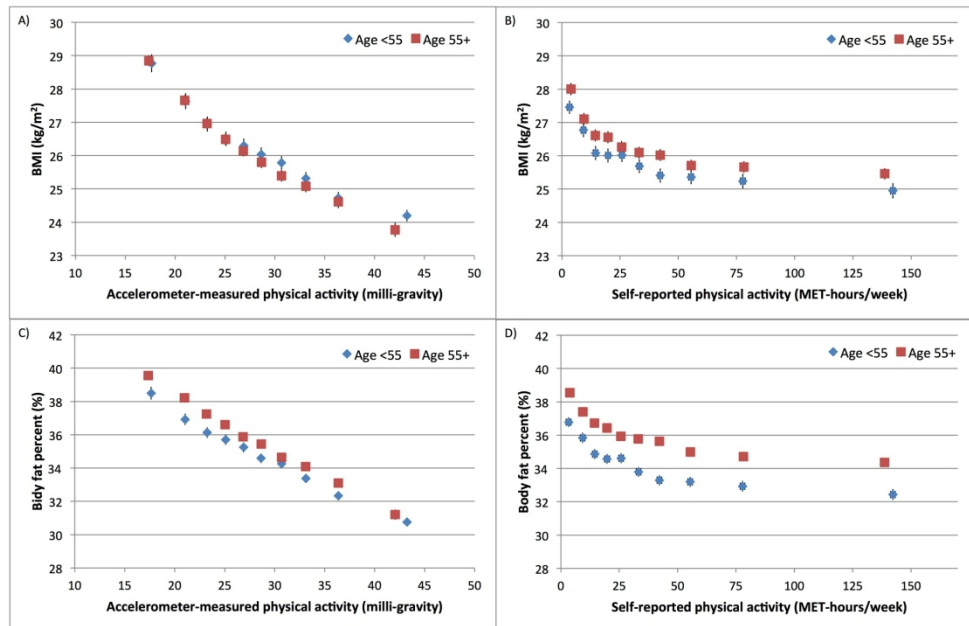
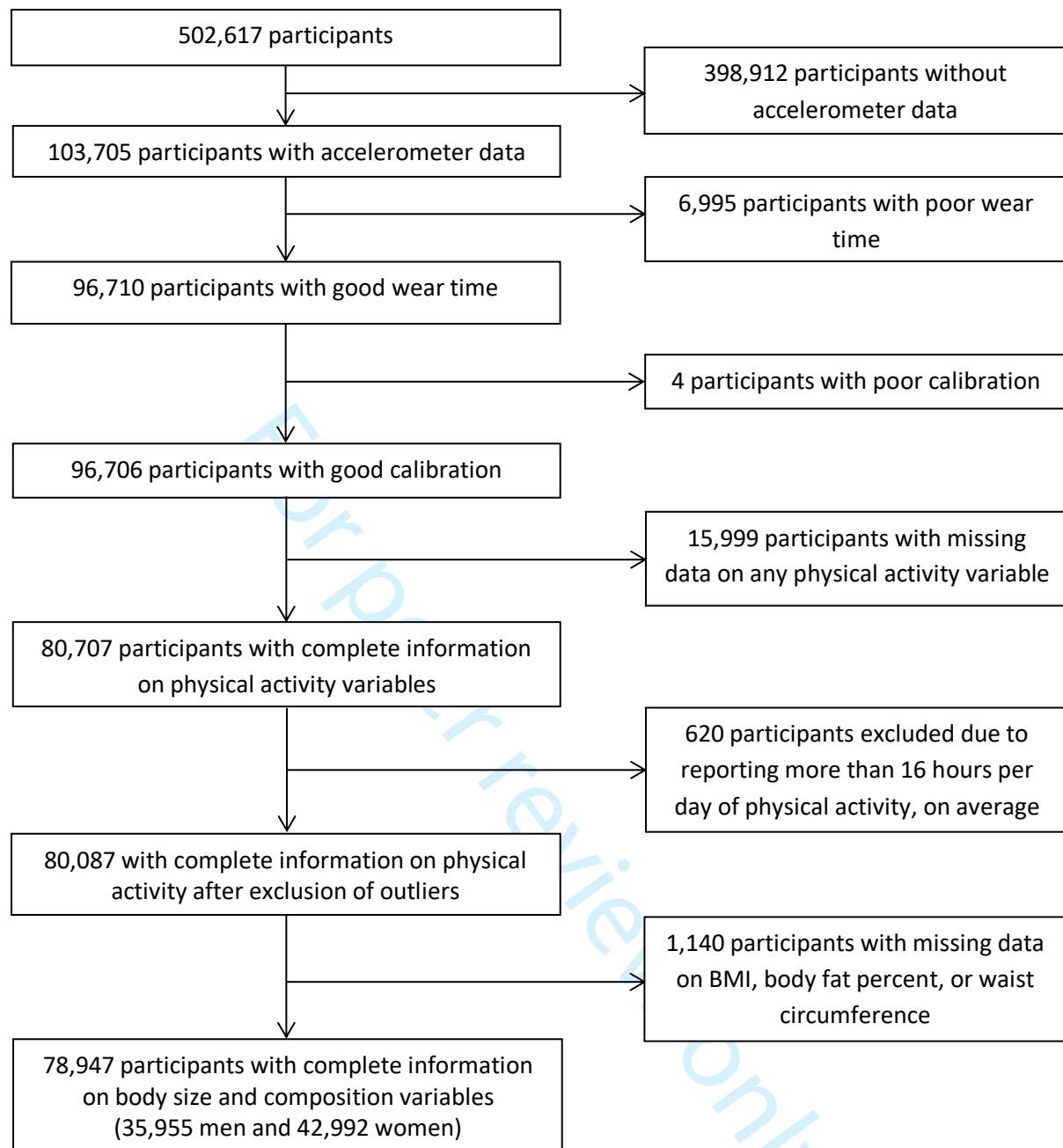


Figure 4. Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank women. Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI. Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent. Physical activity was grouped into tenths. Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for those under age 55 and squares for those ages 55 or older. These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency, parity, and hormone replacement therapy use. The figure shows point estimates and 95% confidence intervals. Abbreviations: BMI, body mass index; MET, metabolic equivalent

195x126mm (300 x 300 DPI)



**Supplementary Table 1. Physical activity questions from the UK Biobank baseline questionnaire**

| Question   | Potential Responses  |
|--|--|
| In a typical WEEK, on how many days did you walk for at least 10 minutes at a time? (Include walking that you do at work, travelling to and from work, and for sport or leisure)                       | Number of days, “Do not know”, “Unable to walk”, or “Prefer not to answer” |
| How many minutes did you usually spend walking on a typical DAY?   | Quantity of minutes, “Do not know”, or “Prefer not to answer”              |
| In a typical WEEK, on how many days did you do 10 minutes or more of moderate physical activities like carrying light loads, cycling at normal pace? (Do not include walking)                          | Number of days, “Do not know”, or “Prefer not to answer”                   |
| How many minutes did you usually spend doing moderate activities on a typical DAY?   | Quantity of minutes, “Do not know”, or “Prefer not to answer”              |
| In a typical WEEK, how many days did you do 10 minutes or more of vigorous physical activity? (These are activities that make you sweat or breathe hard such as fast cycling, aerobics, heavy lifting) | Number of days, “Do not know”, or “Prefer not to answer”                   |
| How many minutes did you usually spend doing vigorous activities on a typical DAY?   | Quantity of minutes, “Do not know”, or “Prefer not to answer”              |

**Supplementary Table 2. Spearman correlation between self-reported physical activity and accelerometer-measured physical activity, according to participant characteristics in UK Biobank men**

|   | <b>N Men (%)</b> | <b>Correlation</b> | <b>95% Confidence Interval</b> |
|---|------------------|--------------------|--------------------------------|
| <b>Total</b>                                | 35,955           | 0.24               | 0.23, 0.25                     |
| <b>Age group at recruitment (years)</b>     |                  |                    |                                |
| <55 years                                   | 13,214 (36.8)    | 0.31               | 0.29, 0.32                     |
| 55+ years                                   | 22,741 (63.3)    | 0.22               | 0.21, 0.23                     |
| <b>Socioeconomic status, fifths</b>         |                  |                    |                                |
| Top fifth                                   | 7,584 (21.1)     | 0.23               | 0.21, 0.25                     |
| Bottom fifth                                | 6,800 (18.9)     | 0.26               | 0.23, 0.28                     |
| <b>BMI (kg/m<sup>2</sup>)</b>               |                  |                    |                                |
| <25   | 10,590 (29.5)    | 0.27               | 0.25, 0.28                     |
| 25-29.9                                     | 17,874 (49.7)    | 0.21               | 0.19, 0.22                     |
| >30   | 7,491 (20.8)     | 0.22               | 0.20, 0.24                     |
| <b>College or university degree</b>         |                  |                    |                                |
| Yes   | 16,709 (46.5)    | 0.25               | 0.24, 0.27                     |
| No  | 19,246 (53.5)    | 0.24               | 0.22, 0.25                     |
| <b>Current employment status</b>            |                  |                    |                                |
| In paid employment or self-employed         | 22,942 (63.8)    | 0.27               | 0.26, 0.28                     |
| Retired                                     | 11,361 (31.6)    | 0.24               | 0.22, 0.26                     |
| Other                                       | 1,652 (4.6)      | 0.30               | 0.26, 0.34                     |
| <b>Job involves mainly walking/standing</b> |                  |                    |                                |
| Never or rarely                             | 9,825 (42.8)     | 0.29               | 0.27, 0.31                     |
| Sometimes                                   | 7,534 (32.9)     | 0.24               | 0.22, 0.26                     |
| Usually or Always                           | 5,574 (24.3)     | 0.19               | 0.16, 0.21                     |
| <b>Job involves heavy manual work</b>       |                  |                    |                                |
| Never, rarely                               | 16,443 (71.7)    | 0.27               | 0.26, 0.29                     |
| Sometimes                                   | 4,160 (18.1)     | 0.17               | 0.14, 0.19                     |
| Usually or Always                           | 2,335 (10.2)     | 0.12               | 0.08, 0.16                     |
| <b>Alcohol intake frequency</b>             |                  |                    |                                |
| Weekly or more                              | 29,421 (81.8)    | 0.23               | 0.22, 0.24                     |
| Less than weekly                            | 6,530 (18.2)     | 0.28               | 0.26, 0.30                     |
| <b>Smoking status</b>                       |                  |                    |                                |
| Never                                       | 18,928 (52.6)    | 0.26               | 0.24, 0.27                     |
| Ever  | 16,964 (47.2)    | 0.22               | 0.21, 0.24                     |
| <b>Long-standing illness or disability</b>  |                  |                    |                                |
| No  | 25,129 (69.9)    | 0.23               | 0.22, 0.24                     |
| Yes   | 10,825 (30.1)    | 0.25               | 0.23, 0.27                     |

**Supplementary Table 3. Spearman correlation between self-reported physical activity and accelerometer-measured physical activity, according to participant characteristics in UK Biobank women**

|   | <b>N Women (%)</b> | <b>Correlation</b> | <b>95% Confidence Interval</b> |
|---|--------------------|--------------------|--------------------------------|
| <b>Total</b>                                | 42,992             | 0.22               | 0.21, 0.23                     |
| <b>Age group at recruitment (years)</b>     |                    |                    |                                |
| <55 years                                   | 18,973 (44.1)      | 0.26               | 0.25, 0.28                     |
| 55+ years                                   | 24,019 (55.9)      | 0.20               | 0.19, 0.22                     |
| <b>Socioeconomic status, fifths</b>         |                    |                    |                                |
| Top fifth                                   | 8,401 (19.5)       | 0.22               | 0.30, 0.24                     |
| Bottom fifth                                | 8,744 (20.3)       | 0.22               | 0.30, 0.24                     |
| <b>BMI (kg/m<sup>2</sup>)</b>               |                    |                    |                                |
| <25   | 20,255 (47.1)      | 0.21               | 0.20, 0.23                     |
| 25-29.9                                     | 15,146 (35.2)      | 0.18               | 0.17, 0.20                     |
| >30   | 7,591 (17.7)       | 0.15               | 0.13, 0.17                     |
| <b>College or university degree</b>         |                    |                    |                                |
| Yes   | 19,214 (44.7)      | 0.22               | 0.21, 0.24                     |
| No  | 23,778 (55.3)      | 0.22               | 0.20, 0.23                     |
| <b>Current employment status</b>            |                    |                    |                                |
| In paid employment or self-employed         | 26,693 (62.1)      | 0.24               | 0.23, 0.25                     |
| Retired                                     | 12,710 (29.6)      | 0.22               | 0.20, 0.24                     |
| Other                                       | 3,589 (8.4)        | 0.30               | 0.27, 0.33                     |
| <b>Job involves mainly walking/standing</b> |                    |                    |                                |
| Never or rarely                             | 12,191 (45.7)      | 0.25               | 0.23, 0.27                     |
| Sometimes                                   | 7,839 (29.4)       | 0.21               | 0.19, 0.23                     |
| Usually or Always                           | 6,648 (24.9)       | 0.18               | 0.16, 0.20                     |
| <b>Job involves heavy manual work</b>       |                    |                    |                                |
| Never, rarely                               | 20,762 (77.8)      | 0.24               | 0.22, 0.25                     |
| Sometimes                                   | 4,353 (16.3)       | 0.17               | 0.14, 0.20                     |
| Usually or Always                           | 1,567 (5.9)        | 0.13               | 0.08, 0.18                     |
| <b>Alcohol intake frequency</b>             |                    |                    |                                |
| Weekly or more                              | 29,829 (69.4)      | 0.22               | 0.21, 0.23                     |
| Less than weekly                            | 13,152 (30.6)      | 0.21               | 0.20, 0.23                     |
| <b>Smoking status</b>                       |                    |                    |                                |
| Never                                       | 25,998 (60.5)      | 0.21               | 0.20, 0.22                     |
| Ever  | 16,936 (39.4)      | 0.23               | 0.22, 0.25                     |
| <b>Long-standing illness or disability</b>  |                    |                    |                                |
| No  | 32,307 (75.2)      | 0.21               | 0.20, 0.22                     |
| Yes   | 10,685 (24.9)      | 0.23               | 0.21, 0.24                     |

Supplementary Table 4. Association of self-reported and accelerometer-measured physical activity with measures of adiposity

|                             | N     | BMI<br>(kg/m <sup>2</sup> ) | 95% CI       | Body fat<br>percent | 95% CI       | Waist<br>circumference<br>(cm) | 95% CI         |
|-----------------------------|-------|-----------------------------|--------------|---------------------|--------------|--------------------------------|----------------|
| <b>Men</b>                  |       |                             |              |                     |              |                                |                |
| <b>Questionnaire</b>        |       |                             |              |                     |              |                                |                |
| Bottom tenth (least active) | 3,643 | 0.00 (reference)            |              | 0.00 (reference)    |              | 0.00 (reference)               |                |
| 2nd tenth                   | 3,742 | -0.69                       | -0.87, -0.52 | -0.99               | -1.23, -0.74 | -1.97                          | -2.45, -1.50   |
| 3rd tenth                   | 3,410 | -0.91                       | -1.09, -0.73 | -1.42               | -1.68, -1.17 | -2.89                          | -3.38, -2.41   |
| 4th tenth                   | 3,677 | -1.22                       | -1.40, -1.05 | -1.97               | -2.22, -1.72 | -3.81                          | -4.29, -3.34   |
| 5th tenth                   | 3,522 | -1.32                       | -1.50, -1.14 | -2.14               | -2.39, -1.88 | -4.47                          | -4.95, -3.99   |
| 6th tenth                   | 3,584 | -1.45                       | -1.63, -1.27 | -2.50               | -2.75, -2.24 | -4.79                          | -5.27, -4.31   |
| 7th tenth                   | 3,596 | -1.59                       | -1.76, -1.41 | -2.88               | -3.13, -2.63 | -5.41                          | -5.89, -4.93   |
| 8th tenth                   | 3,591 | -1.63                       | -1.81, -1.45 | -3.09               | -3.34, -2.83 | -5.92                          | -6.40, -5.44   |
| 9th tenth                   | 3,595 | -1.71                       | -1.89, -1.53 | -3.21               | -3.46, -2.95 | -6.33                          | -6.81, -5.85   |
| Top tenth (most active)     | 3,595 | -1.77                       | -1.95, -1.59 | -3.56               | -3.81, -3.31 | -6.42                          | -6.90, -5.93   |
| <b>Accelerometer</b>        |       |                             |              |                     |              |                                |                |
| Bottom tenth (least active) | 3,598 | 0.00 (reference)            |              | 0.00 (reference)    |              | 0.00 (reference)               |                |
| 2nd tenth                   | 3,604 | -0.77                       | -0.95, -0.60 | -0.99               | -1.24, -0.75 | -2.23                          | -2.70, -1.76   |
| 3rd tenth                   | 3,592 | -1.33                       | -1.50, -1.15 | -1.83               | -2.07, -1.58 | -3.69                          | -4.16, -3.22   |
| 4th tenth                   | 3,610 | -1.60                       | -1.77, -1.42 | -2.20               | -2.45, -1.95 | -4.59                          | -5.06, -4.12   |
| 5th tenth                   | 3,597 | -1.88                       | -2.06, -1.71 | -2.69               | -2.94, -2.44 | -5.43                          | -5.90, -4.96   |
| 6th tenth                   | 3,585 | -2.07                       | -2.24, -1.89 | -3.04               | -3.28, -2.79 | -6.00                          | -6.47, -5.53   |
| 7th tenth                   | 3,589 | -2.32                       | -2.49, -2.14 | -3.52               | -3.77, -3.27 | -7.01                          | -7.49, -6.54   |
| 8th tenth                   | 3,594 | -2.57                       | -2.75, -2.39 | -3.84               | -4.09, -3.59 | -7.69                          | -8.17, -7.22   |
| 9th tenth                   | 3,591 | -3.02                       | -3.20, -2.84 | -4.75               | -5.00, -4.50 | -9.01                          | -9.48, -8.53   |
| Top tenth (most active)     | 3,595 | -3.61                       | -3.79, -3.43 | -5.98               | -6.24, -5.73 | -11.23                         | -11.72, -10.75 |



|                             |       |                  |              |                  |              |                  |                |
|-----------------------------|-------|------------------|--------------|------------------|--------------|------------------|----------------|
|                             |       |                  |              |                  |              |                  |                |
| <b>Women</b>                |       |                  |              |                  |              |                  |                |
| <b>Questionnaire</b>        |       |                  |              |                  |              |                  |                |
| Bottom tenth (least active) | 4,433 | 0.00 (reference) |              | 0.00 (reference) |              | 0.00 (reference) |                |
| 2nd tenth                   | 4,187 | -0.81            | -1.00, -0.61 | -1.05            | -1.33, -0.78 | -1.77            | -2.25, -1.29   |
| 3rd tenth                   | 4,278 | -1.37            | -1.57, -1.18 | -1.89            | -2.16, -1.61 | -3.33            | -3.81, -2.86   |
| 4th tenth                   | 4,318 | -1.44            | -1.64, -1.25 | -2.16            | -2.43, -1.88 | -3.74            | -4.22, -3.27   |
| 5th tenth                   | 4,296 | -1.60            | -1.79, -1.40 | -2.44            | -2.72, -2.17 | -3.92            | -4.39, -3.44   |
| 6th tenth                   | 4,308 | -1.86            | -2.05, -1.66 | -2.89            | -3.16, -2.61 | -4.71            | -5.18, -4.23   |
| 7th tenth                   | 4,276 | -1.98            | -2.18, -1.79 | -3.18            | -3.45, -2.90 | -5.02            | -5.50, -4.55   |
| 8th tenth                   | 4,300 | -2.20            | -2.39, -2.00 | -3.57            | -3.85, -3.30 | -5.73            | -6.20, -5.25   |
| 9th tenth                   | 4,305 | -2.28            | -2.48, -2.09 | -3.86            | -4.14, -3.59 | -5.91            | -6.39, -5.44   |
| Top tenth (most active)     | 4,291 | -2.51            | -2.70, -2.31 | -4.25            | -4.52, -3.97 | -6.39            | -6.87, -5.91   |
| <b>Accelerometer</b>        |       |                  |              |                  |              |                  |                |
| Bottom tenth (least active) | 4,314 | 0.00 (reference) |              | 0.00 (reference) |              | 0.00 (reference) |                |
| 2nd tenth                   | 4,292 | -1.14            | -1.33, -0.95 | -1.43            | -1.70, -1.16 | -3.02            | -3.49, -2.56   |
| 3rd tenth                   | 4,293 | -1.84            | -2.03, -1.65 | -2.35            | -2.62, -2.09 | -4.42            | -4.89, -3.95   |
| 4th tenth                   | 4,307 | -2.31            | -2.50, -2.12 | -2.90            | -3.17, -2.63 | -5.43            | -5.90, -4.97   |
| 5th tenth                   | 4,312 | -2.60            | -2.79, -2.41 | -3.52            | -3.79, -3.25 | -6.27            | -6.74, -5.80   |
| 6th tenth                   | 4,286 | -2.92            | -3.11, -2.72 | -4.05            | -4.32, -3.79 | -7.18            | -7.65, -6.71   |
| 7th tenth                   | 4,292 | -3.22            | -3.42, -3.04 | -4.63            | -4.90, -4.36 | -7.88            | -8.35, -7.41   |
| 8th tenth                   | 4,301 | -3.60            | -3.80, -3.41 | -5.34            | -5.61, -5.07 | -8.80            | -9.27, -8.33   |
| 9th tenth                   | 4,305 | -4.17            | -4.36, -3.98 | -6.37            | -6.64, -6.10 | -10.12           | -10.59, -9.64  |
| Top tenth (most active)     | 4,290 | -4.80            | -4.99, -4.60 | -8.06            | -8.33, -7.78 | -11.92           | -12.39, -11.44 |

Analyses are adjusted for age, socioeconomic status, alcohol intake, smoking status, educational qualifications, and employment status. Analyses are further adjusted for parity and hormone replacement therapy use in women.

**Supplementary Table 5. Association of accelerometer-measured physical activity with body fat percent, measured by bioelectrical impedance and dual energy X-ray absorptiometry (DXA) in UK Biobank**

| Accelerometer-measured physical activity | N   | Mean body fat percent | 95% CI     | Coefficient            | 95% CI       |
|--|-----|-----------------------|------------|------------------------|--------------|
| <b>Men</b>                               |     |                       |            |                        |              |
| <b>Measured by impedance</b>             |     |                       |            |                        |              |
| Bottom fifth (least active)              | 237 | 27.4                  | 26.7, 28.0 | 0.00 (reference group) |              |
| 2nd fifth                                | 231 | 26.0                  | 25.3, 26.6 | -1.29                  | -2.21, -0.38 |
| 3rd fifth                                | 229 | 24.7                  | 24.0, 25.3 | -2.63                  | -3.55, -1.71 |
| 4th fifth                                | 253 | 23.8                  | 23.1, 24.4 | -3.46                  | -4.36, -2.56 |
| Top fifth (most active)                  | 235 | 21.8                  | 21.1, 22.4 | -5.51                  | -6.45, -4.58 |
| <b>Men</b>                               |     |                       |            |                        |              |
| <b>Measured by DXA</b>                   |     |                       |            |                        |              |
| Bottom fifth (least active)              | 237 | 34.1                  | 33.3, 34.8 | 0.00 (reference group) |              |
| 2nd fifth                                | 231 | 31.6                  | 30.9, 32.4 | -2.38                  | -3.45, -1.31 |
| 3rd fifth                                | 229 | 30.0                  | 29.2, 30.7 | -4.12                  | -5.20, -3.05 |
| 4th fifth                                | 253 | 28.7                  | 28.0, 29.4 | -5.48                  | -6.54, -4.42 |
| Top fifth (most active)                  | 235 | 26.1                  | 25.4, 26.9 | -8.18                  | -9.27, -7.08 |
| <b>Women</b>                             |     |                       |            |                        |              |
| <b>Measured by impedance</b>             |     |                       |            |                        |              |
| Bottom fifth (least active)              | 270 | 38.4                  | 37.6, 39.1 | 0.00 (reference group) |              |
| 2nd fifth                                | 244 | 36.6                  | 35.9, 37.4 | -1.46                  | -2.55, -0.37 |
| 3rd fifth                                | 265 | 36.1                  | 35.4, 36.9 | -1.93                  | -3.01, -0.85 |
| 4th fifth                                | 228 | 34.5                  | 33.7, 35.3 | -3.43                  | -4.55, -2.31 |
| Top fifth (most active)                  | 265 | 30.8                  | 30.1, 31.6 | -6.97                  | -8.07, -5.87 |
| <b>Women</b>                             |     |                       |            |                        |              |
| <b>Measured by DXA</b>                   |     |                       |            |                        |              |
| Bottom fifth (least active)              | 270 | 42.5                  | 41.7, 43.3 | 0.00 (reference group) |              |
| 2nd fifth                                | 244 | 40.4                  | 39.6, 41.2 | -1.87                  | -3.04, -0.71 |
| 3rd fifth                                | 265 | 39.8                  | 39.0, 40.6 | -2.55                  | -3.70, -1.40 |
| 4th fifth                                | 228 | 37.1                  | 36.2, 37.9 | -4.98                  | -6.17, -3.78 |
| Top fifth (most active)                  | 265 | 33.3                  | 32.5, 34.1 | -8.83                  | -10.0, -7.65 |

Analyses are adjusted for age, socioeconomic status, alcohol intake, smoking status, educational qualifications, and employment status. Analyses are further adjusted for parity and hormone replacement therapy use in women.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   |
|------------------------------|---------|--|
| <b>Title and abstract</b>    | 1       | <input checked="" type="checkbox"/> (a) Indicate the study's design with a commonly used term in the title or the abstract <a href="#">pages 1-2</a><br><input checked="" type="checkbox"/> (b) Provide in the abstract an informative and balanced summary of what was done and what was found <a href="#">pages 2-3</a>  |
| <b>Introduction</b>          |         |  |
| Background/rationale         | 2       | <input checked="" type="checkbox"/> Explain the scientific background and rationale for the investigation being reported <a href="#">page 4</a>  |
| Objectives                   | 3       | <input checked="" type="checkbox"/> State specific objectives, including any prespecified hypotheses <a href="#">page 4</a>  |
| <b>Methods</b>               |         |  |
| Study design                 | 4       | <input checked="" type="checkbox"/> Present key elements of study design early in the paper <a href="#">pages 5-9</a>  |
| Setting                      | 5       | <input checked="" type="checkbox"/> Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection <a href="#">pages 5-7</a>  |
| Participants                 | 6       | <input checked="" type="checkbox"/> (a) Give the eligibility criteria, and the sources and methods of selection of participants <a href="#">pages 5-6</a>  |
| Variables                    | 7       | <input checked="" type="checkbox"/> Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable <a href="#">pages 6-8</a>   |
| Data sources/<br>measurement | 8*      | <input checked="" type="checkbox"/> 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 <a href="#">pages 6-7</a>   |
| Bias                         | 9       | <input checked="" type="checkbox"/> Describe any efforts to address potential sources of bias <a href="#">page 4</a>   |
| Study size                   | 10      | <input checked="" type="checkbox"/> Explain how the study size was arrived at <a href="#">pages 5-6</a>  |
| Quantitative variables       | 11      | <input checked="" type="checkbox"/> Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why <a href="#">pages 6-8</a>   |
| Statistical methods          | 12      | <input checked="" type="checkbox"/> (a) Describe all statistical methods, including those used to control for confounding <a href="#">pages 7-9</a><br><input checked="" type="checkbox"/> (b) Describe any methods used to examine subgroups and interactions <a href="#">pages 8-9</a><br><input checked="" type="checkbox"/> (c) Explain how missing data were addressed <a href="#">pages 8-9</a><br>N/A (d) If applicable, describe analytical methods taking account of sampling strategy<br><input checked="" type="checkbox"/> (e) Describe any sensitivity analyses <a href="#">pages 8-9</a> |
| <b>Results</b>               |         |  |
| Participants                 | 13*     | <input checked="" type="checkbox"/> (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 <a href="#">page 9 and Supplementary Figure 1</a><br><input checked="" type="checkbox"/> (b) Give reasons for non-participation at each stage <a href="#">Supplementary Figure 1</a><br><input checked="" type="checkbox"/> (c) Consider use of a flow diagram <a href="#">Supplementary Figure 1</a>  |
| Descriptive data             | 14*     | <input checked="" type="checkbox"/> (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders <a href="#">pages 9-10</a><br><input checked="" type="checkbox"/> (b) Indicate number of participants with missing data for each variable of interest <a href="#">pages 5-6, Supplementary Figure 1</a>   |
| Outcome data                 | 15*     | <input checked="" type="checkbox"/> Report numbers of outcome events or summary measures <a href="#">pages 10-12, figures</a>  |
| Main results                 | 16      | <input checked="" type="checkbox"/> (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 <a href="#">page 8, figures, supplementary tables,</a>  |

|                          |    |  |
|--------------------------|----|--|
|                          |    | <a href="#">22-24 (figure legends)</a>   |
|                          |    | <input checked="" type="checkbox"/> (b) Report category boundaries when continuous variables were categorized <a href="#">page 9</a>   |
|                          |    | N/A (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   |
| Other analyses           | 17 | <input checked="" type="checkbox"/> Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses <a href="#">pages 11-12</a>   |
| <b>Discussion</b>        |    |  |
| Key results              | 18 | <input checked="" type="checkbox"/> Summarise key results with reference to study objectives <a href="#">pages 12-13</a>   |
| Limitations              | 19 | <input checked="" type="checkbox"/> Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias <a href="#">pages 15-16</a>                 |
| Interpretation           | 20 | <input checked="" type="checkbox"/> Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence <a href="#">pages 13-16</a> |
| Generalisability         | 21 | <input checked="" type="checkbox"/> Discuss the generalisability (external validity) of the study results <a href="#">page 16</a>  |
| <b>Other information</b> |    |  |
| Funding                  | 22 | <input checked="" type="checkbox"/> 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 <a href="#">page 16</a>                  |

\*Give information separately for exposed and unexposed groups.

**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](http://www.strobe-statement.org).

# BMJ Open

## Accelerometer compared with questionnaire measures of physical activity in relation to body size and composition: a large cross-sectional analysis of UK Biobank

|                                 |   |
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3 **Accelerometer compared with questionnaire measures of physical activity in relation to**  
4 **body size and composition: a large cross-sectional analysis of UK Biobank**  
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45 Abbreviations: body mass index (BMI), confidence interval (CI), dual-energy X-ray  
46 absorptiometry (DXA), International Physical Activity Questionnaire (IPAQ), metabolic  
47 equivalents (METs), standard deviation (SD)  
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## Abstract

**Objectives:** Previous studies of the association between physical activity and adiposity are largely based on physical activity and body mass index (BMI) from questionnaires, which are prone to inaccurate and biased reporting. We assessed the associations of accelerometer-measured and questionnaire-measured physical activity with BMI, waist circumference and body fat percent measured by bioelectrical impedance and dual-energy X-ray absorptiometry (DXA).

**Design:** Cross-sectional analysis of UK Biobank participants

**Setting:** UK Biobank assessment centers

**Participants:** 78,947 UK Biobank participants (35,955 men and 42,992 women) aged 40-70 at recruitment, who had physical activity measured by both questionnaire and accelerometer.

**Main outcome measures:** BMI, waist circumference and body fat percent measured by bioelectrical impedance

**Results:** Greater physical activity was associated with lower adiposity. Women in the top tenth of accelerometer-measured physical activity had a 4.8 (95% CI: 4.6, 5.0) kg/m<sup>2</sup> lower BMI, 8.1% (95% CI: 7.8, 8.3) lower body fat percent, and 11.9 (95% CI 11.4, 12.4) cm lower waist circumference. Women in the top tenth of questionnaire-measured physical activity had a 2.5 (95% CI: 2.3, 2.7) kg/m<sup>2</sup> lower BMI, 4.3% (95% CI: 4.0, 4.5) lower body fat percent, and 6.4 (95% CI: 5.9, 6.9) cm lower waist circumference, compared to women in the bottom tenths. The patterns were similar in men and also similar with body fat percent measured by DXA compared to impedance.

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3 **Conclusion:** Our findings of approximately twofold stronger associations between physical  
4 activity and adiposity with objectively-measured than with self-reported physical activity  
5 emphasize the need to incorporate objective measures in future studies.  
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14 **Strengths and limitations of this study:**  
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- 18 • This study utilizes data on physical activity objectively measured by accelerometer  
19 rather than only self-reported data from questionnaires, which may be prone to  
20 inaccurate and potentially biased reporting.  
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  - 23 • This study is by far the largest study to examine associations of objectively measured  
24 physical activity and self-reported physical activity with various measures of  
25 adiposity, including body fat percent assessed by bioelectrical impedance and dual  
26 energy x-ray absorptiometry.  
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  - 29 • Due to the cross-sectional nature of this study, we cannot assess to what extent  
30 physical activity is causally related to adiposity.  
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## INTRODUCTION

The prevalence of overweight and obesity is high worldwide and is associated with increased risk of various conditions including heart disease, stroke, hypertension, diabetes, and some cancers (1, 2). Although physical activity is generally accepted to be important for prevention of weight gain, achievement of modest weight loss, and prevention of weight regain after weight loss (3), randomized controlled trials have shown inconsistent results, perhaps partly due to limited duration of interventions and difficulty in long-term adherence to exercise regimens (4), and previous large-scale observational studies are mostly based on self-reported physical activity from questionnaires, which are prone to both inaccurate reporting and reporting bias (5).

Prior studies have demonstrated low to moderate correlation between self-reported and objective accelerometer measures of physical activity (6, 7). Self-reported and accelerometer-measured physical activity capture different aspects of physical activity with limitations unique to each (7). However, research methods utilizing more objective measures of physical activity, along with more detailed measures of body fat, are needed to reduce measurement error and more accurately characterize the association between physical activity and adiposity.

We examined the association between physical activity and adiposity, with accelerometer-measured compared to self-reported physical activity in nearly 80,000 participants. These associations were assessed using various measures of adiposity, including BMI, waist circumference, and body fat percent measured by both bioelectrical impedance and dual-energy X-ray absorptiometry (DXA). We also explored how the associations vary by age.

## METHODS

### Data source

Data were obtained from UK Biobank. Details of UK Biobank design, rationale, and survey methods have been described elsewhere (8). Information on data available and access procedures are described on the study website (<http://www.ukbiobank.ac.uk/>). UK Biobank has approval from the National Information Governance Board for Health & Social Care in England and Wales, the North West Multi-centre Research Ethics Committee, and the Community Health Index Advisory Group in Scotland. Written informed consent was provided by all participants.

### Study participants

The complete UK Biobank dataset includes 502,617 UK adults (229,164 men and 273,453 women) between 40 to 70 years of age at recruitment during 2006 to 2010. During the baseline assessment center visit, participants completed a touchscreen questionnaire which included questions on socio-demographics, lifestyle, health and medical history, and sex-specific factors. The present study was restricted to participants with available accelerometer data (n=103,705). Participants were excluded if they did not have at least 72 hours of data and also data in each one-hour period of the 24-hour cycle across multiple days (n=6,995). Participants were also excluded if they had insufficient data for calibration (n=4). Participants who had missing data on any of the physical activity variables used in our analyses were excluded (n=15,999). Participants who reported physical activity greater than an average of 16 hours per day (n=620) were also excluded as recommended by the International Physical Activity Questionnaire (IPAQ) scoring guidelines, which can be accessed at <file:///H:/Downloads/GuidelinesforDataProcessingandAnalysisoftheInternationalPhysicalActivityQuestionnaireIPAQShortandLongForms.pdf>. Finally, participants with missing data on

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3 BMI (n=146), body fat percent (n=988), and waist circumference (n=6) were excluded. The  
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5 analyses included 35,955 men and 42,992 women (**Supplementary Figure 1**).  
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### 8 Self-reported physical activity 9

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11 Physical activity questions from the baseline questionnaire captured the frequency and  
12 duration of three intensities of activity (walking, moderate, and vigorous). Participants were  
13 asked how many days per week they typically engaged in each category of activity. For each  
14 category in which an answer of one or more days was given, the participant was subsequently  
15 asked the number of minutes on average spent on the activity per day. Questions were  
16 adapted from the IPAQ, a validated survey instrument (9), and are listed in **Supplementary**  
17 **Table 1**. Metabolic equivalents (METs) were used to quantify physical activity; 1 MET is  
18 expended by sitting quietly for 1 hour, and the MET value reflects the ratio of energy  
19 expended per kilogram of body weight per hour to that expended when sitting quietly (10).  
20 The number of minutes per day engaged in each level of activity was multiplied by the  
21 respective MET score for the corresponding level of activity (3.3 for walking, 4.0 for  
22 moderate physical activity, and 8.0 for vigorous physical activity) (11). MET minutes per day  
23 were converted to MET hours per week. The total amount of METs was calculated by  
24 summing total METs from the walking, moderate, and vigorous activity levels. Following  
25 IPAQ scoring guidelines, physical activity of less than 10 minutes per day for any category  
26 was recoded to 0.  
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### 48 Accelerometer-measured physical activity 49

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51 A total of 236,519 participants, all of whom had provided a valid email address, were  
52 invited to participate in a seven day accelerometer study between February 2013 and  
53 December 2015 (on average, approximately 5.5 years after recruitment when baseline  
54 physical activity was self-reported). Starting in June 2013, participants were sent wrist-worn  
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3 triaxial accelerometers (Axivity AX3, Newcastle upon Tyne, UK) that were programmed to  
4 capture three-dimensional acceleration data at 100 Hz with a dynamic range of  $\pm 8$  g.  
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7 Participants were also given instructions to wear the accelerometer on their dominant wrist  
8 continuously for seven days and then to send the device to the coordinating center using the  
9 provided prepaid envelope. Further details on data collection, processing, and analysis can be  
10 found elsewhere (12). We used the “overall acceleration average” variable (data field 90012)  
11 in the present analyses.  
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## 20 Anthropometry and body composition

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23 At the UK Biobank baseline interview, trained staff measured standing height using the  
24 Seca 202 device (Seca, Hamburg, Germany). BMI was calculated by dividing weight (kg) by  
25 the square of standing height ( $m^2$ ). The Wessex non-stretchable sprung tape measure  
26 (Wessex, United Kingdom) was used to measure waist circumference at the level of the  
27 umbilicus. The Tanita BC-418MA body composition analyzer (Tanita, Tokyo, Japan) was  
28 used to measure body fat percent using bioelectrical impedance. DXA was used to measure  
29 fat percent on a subset of 2,457 participants included in the present study, beginning in 2014  
30 using the GE-Lunar iDXA (GE Healthcare, Chicago, USA).  
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## 42 Statistical analyses

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45 Baseline characteristics were summarized by physical activity (least active fifth, most  
46 active fifth, and overall) separately for men and women. Since self-reported physical activity  
47 was not normally distributed, Spearman’s correlation coefficients were used to measure the  
48 strength of correlations between self-reported and accelerometer-measured physical activity  
49 in the overall population and in subgroups based on sociodemographic characteristics.  
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3 Self-reported and accelerometer-measured physical activity were categorized into tenths  
4 and the median value within each category of physical activity is shown in the figures. The  
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6 and the median value within each category of physical activity is shown in the figures. The  
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8 associations of physical activity and adiposity measures were examined using multivariable  
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10 linear regression, separately in men and women. Analyses comparing the association of  
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12 accelerometer-measured physical activity with body fat percent, measured by bioelectrical  
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14 impedance and DXA were restricted to participants with both measures. Likelihood ratio tests  
15  
16 were used to assess whether the associations between physical activity and adiposity were  
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18 modified by age (<55 years or 55+ years), separately for self-reported and accelerometer-  
19  
20 measured physical activity.  
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25 Covariates were determined a priori and were 5-year age at recruitment categories,  
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27 socioeconomic status as indicated by fifths of Townsend deprivation index (13), educational  
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29 qualifications, employment status, smoking status (never, previous, current), and alcohol  
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31 intake frequency. Analyses in women were additionally adjusted for parity (nulliparous, 1, 2,  
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33 3, 4 or more births) and hormone replacement therapy use (never, previous, current). As a  
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35 covariate, educational qualification was grouped into the following categories: vocational  
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37 qualifications, national exams at age 16 (O levels, GCSEs, CSEs, or equivalent), optional  
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39 national exams at ages 17-18 years (A levels, AS levels, or equivalent), and college or  
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41 university degree. Employment status was categorized as paid or self-employed, retired,  
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43 looking after home and/or family, unemployed, doing unpaid or voluntary work, unable to  
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45 work due to sickness or disability, and student. Alcohol intake was categorized as never,  
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47 special occasions only, 1-3 times a month, 1-2 times a week, 3-4 times a week, and daily or  
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49 almost daily.  
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55 Missing data were grouped in a separate unknown category for each covariate. There were  
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57 less than 1% missing data for all covariates except for educational qualifications (7.4%  
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59 missing data). To assess the impact of missing values, a sensitivity analysis restricted to  
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participants with known values for all covariates was conducted. We also conducted sensitivity analyses to assess the impact of excluding participants who reported long-term illness, disability or infirmity, participants who reported fair or poor health rather than excellent or good health, and participants whose jobs usually or always required heavy manual work. Analyses were conducted using STATA, version 15.0 (Stata Corp LP, College Station, TX).

#### Patient and public involvement

This study did not involve patients and the public.

## RESULTS

Characteristics of the study population by least active and most active fifth of accelerometer-measured physical activity are shown in **Table 1**.

**Table 1. Characteristics of the UK Biobank study population, according to fifths of accelerometer-measured physical activity.**

|  | Least active men    | Most active men     | All men           | Least active women  | Most active women   | All women         |
|--|---------------------|---------------------|-------------------|---------------------|---------------------|-------------------|
|  | <20.8 milli-gravity | ≥33.7 milli-gravity |                   | <22.2 milli-gravity | ≥34.6 milli-gravity |                   |
| <b>Number of participants</b>  | 7,202               | 7,186               | 35,955            | 8,606               | 8,595               | 42,992            |
| <b>Age at recruitment (years), mean (SD)</b>                               | 59.7 (7.0)          | 53.4 (7.7)          | 56.7 (7.9)        | 58.0 (7.4)          | 52.6 (7.4)          | 55.3 (7.7)        |
| <b>Lowest fifth of socioeconomic status</b>                                | 1,520 (21.1%)       | 1,351 (18.8%)       | 6,800 (18.9%)     | 1,897 (22.0%)       | 1,699 (19.8%)       | 8,744 (20.3%)     |
| <b>Accelerometer-measured physical activity (milli-gravity), mean (SD)</b> | 17.5 (2.6)          | 40.5 (7.8)          | 27.6 (8.7)        | 18.9 (2.7)          | 40.6 (6.3)          | 28.7 (8.0)        |
| <b>Self-reported physical activity (MET-hours/week), median (IQR)</b>      | 20.7 (9.0, 42.6)    | 44.2 (23.7, 80.9)   | 29.9 (14.2, 58.1) | 21.3 (9.9, 41.7)    | 40.2 (21.8, 73.2)   | 29.3 (14.4, 55.3) |
| <b>Height (cm), mean (SD)</b>  | 176.3 (6.8)         | 176.4 (6.6)         | 176.5 (6.6)       | 163.2 (6.3)         | 163.7 (6.1)         | 163.5 (6.2)       |
| <b>Weight (kg), mean (SD)</b>  | 89.4 (15.4)         | 80.8 (11.4)         | 84.9 (13.5)       | 75.5 (15.6)         | 65.0 (10.3)         | 69.9 (13.2)       |
| <b>BMI (kg/m<sup>2</sup>), mean (SD)</b>                                   | 28.8 (4.6)          | 25.9 (3.3)          | 27.2 (4.0)        | 28.3 (5.7)          | 24.3 (3.7)          | 26.2 (4.8)        |
| <b>Body fat percent (%) <sup>a</sup>, mean (SD)</b>                        | 27.0 (5.6)          | 21.7 (5.4)          | 24.4 (5.7)        | 38.7 (6.6)          | 31.7 (6.4)          | 35.3 (6.8)        |
| <b>Waist circumference (cm), mean (SD)</b>                                 | 100.1 (11.7)        | 90.9 (9.3)          | 95.4 (10.8)       | 87.9 (13.3)         | 77.6 (9.5)          | 82.4 (11.7)       |

|   |                  |                  |                   |                  |                  |                   |
|---|------------------|------------------|-------------------|------------------|------------------|-------------------|
| <b>College or university degree</b>                     | 3,018<br>(41.9%) | 3,365<br>(46.8%) | 16,709<br>(46.5%) | 3,586<br>(41.7%) | 4,060<br>(47.2%) | 19,214<br>(44.7%) |
| <b>Current employment status</b>                        |                  |                  |                   |                  |                  |                   |
| Paid employment/self-employed                           | 3,608<br>(50.1%) | 5,420<br>(75.4%) | 22,942<br>(63.8%) | 4,401<br>(51.1%) | 6,101<br>(71.0%) | 26,693<br>(62.1%) |
| Retired   | 3,107<br>(43.1%) | 1,451<br>(20.2%) | 11,361<br>(31.6%) | 3,517<br>(40.9%) | 1,591<br>(18.5%) | 12,710<br>(29.6%) |
| Other   | 487 (6.8%)       | 315 (4.4%)       | 1,652<br>(4.6%)   | 688 (8.0%)       | 903 (10.5%)      | 3,589<br>(8.3%)   |
| <b>Job involves mainly walking/standing<sup>b</sup></b> | 707 (19.6%)      | 1,742<br>(32.1%) | 5,574<br>(24.3%)  | 893 (20.3%)      | 1,926<br>(31.6%) | 6,648<br>(24.9%)  |
| <b>Job involves heavy manual work<sup>c</sup></b>       | 272 (7.5%)       | 912<br>(16.8%)   | 2,335<br>(10.2%)  | 170 (3.9%)       | 576 (9.4%)       | 1,567<br>(5.9%)   |
| <b>Weekly or more frequent alcohol intake</b>           | 5,545<br>(77.0%) | 5,989<br>(83.3%) | 29,421<br>(81.8%) | 5,295<br>(61.5%) | 6,292<br>(73.2%) | 29,829<br>(69.4%) |
| <b>Ever smoker</b>                                      | 3,801<br>(52.8%) | 3,126<br>(43.5%) | 16,964<br>(47.2%) | 3,583<br>(41.6%) | 3,212<br>(37.4%) | 16,936<br>(39.4%) |
| <b>Long-standing illness or disability</b>              | 3,089<br>(42.9%) | 1,543<br>(21.5%) | 10,825<br>(30.1%) | 3,145<br>(36.5%) | 1,449<br>(16.9%) | 1,0685<br>(24.9%) |

<sup>a</sup> Body fat percent was measured by bioelectrical impedance

<sup>b</sup> Participants who reported their work “usually” or “always” involved walking or standing for most of the time

<sup>c</sup> Participants who reported their work “usually” or “always” involved heavy manual or physical work for most of the time

Mean accelerometer-measured physical activity was 27.6 (standard deviation [SD] 8.7) milli-gravity in men and 28.7 (SD 8.0) milli-gravity in women. The most active participants were on average younger and had lower values for all body size and composition variables. They were more likely to have a college or university degree, be employed rather than retired, have an active job, and consume alcohol at least weekly. The least active participants were more likely to be ever smokers and were also more likely to have a long-standing illness or disability. The correlation between questionnaire and accelerometer-measured physical activity, recorded on average 5.5 years later, was 0.24 (95% confidence interval [CI]: 0.23, 0.25) in men (**Supplementary Table 2**) and 0.22 (95% CI: 0.21, 0.23) in women (**Supplementary Table 3**). The correlations were comparatively higher in participants who were younger and in participants who had lower BMI. The correlations were lower among

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3 participants who reported that their job usually or always involved heavy manual work and/or  
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5 mainly walking or standing.  
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9 The inverse associations between physical activity and all measures of adiposity were  
10 linear and approximately twofold larger in models that used accelerometer-measured rather  
11 than self-reported physical activity. Since there was heterogeneity in the associations between  
12 both self-reported and accelerometer-measured physical activity and adiposity by sex  
13 ( $P < 0.001$ ), separate analyses were performed in men and women. The mean differences in  
14 BMI and body fat percent were greater in women compared to men. Comparing the top to  
15 bottom tenth of accelerometer-measured physical activity, the difference in BMI was 4.8  
16 (95% CI: 4.6, 5.0) kg/m<sup>2</sup> in women and 3.6 (95% CI: 3.4, 3.8) kg/m<sup>2</sup> in men (**Figure 1,**  
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27 **Supplementary Table 4**).

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Women in the top tenth of accelerometer-measured physical activity had an 8.1% (95%  
CI: 7.8, 8.3) lower body fat percent while women in the top tenth of self-reported physical  
activity had a 4.3% (95% CI: 4.0, 4.5) lower body fat percent, compared to those in the  
bottom tenth of physical activity. Men in the top tenth of accelerometer-measured physical  
activity had a 6.0% (95% CI: 5.7, 6.2) lower body fat percent while men in the top tenth of  
self-reported physical activity had a 3.6% (95% CI: 3.3, 3.8) lower body fat percent,  
compared to those in the bottom tenth (**Figure 1, Supplementary Table 4**).

Associations between physical activity and waist circumference were of similar magnitude  
in men and women, with an approximately twofold larger inverse association between waist  
circumference and physical activity when measured by accelerometer rather than  
questionnaire (**Figure 1, Supplementary Table 4**).

The results of sensitivity analyses excluding participants who had any missing values,  
reported a long-term illness or disability, reported a health rating worse than “good”, or



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3 whose jobs usually or always required heavy manual work did not materially differ from the  
4  
5 main findings.  
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9 **Figure 2 and Supplementary Table 5** show the associations between accelerometer-  
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11 measured physical activity and bioelectrical impedance-measured body fat percent at baseline  
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13 (2006-2010) compared to body fat percent measured by DXA starting in May 2014. Body fat  
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15 percent by impedance at baseline was lower than body fat percent by DXA, measured on  
16  
17 average seven years later. For both measures, there was a linear dose-response association  
18  
19 between physical activity and body fat percent in both men and women. The inverse  
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21 associations were stronger when body fat percent was measured by DXA. Compared to the  
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23 least active women, the most active women had an 8.8% (95% CI: 7.7, 10.0) lower DXA-  
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25 measured body fat percent and a 7.0% (95% CI: 5.9, 8.1) lower impedance-measured body  
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27 fat percent and a 7.0% (95% CI: 5.9, 8.1) lower impedance-measured body  
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29 fat percent (**Figure 2 and Supplementary Table 5**).  
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33 Associations between physical activity and measures of adiposity by age group are shown  
34  
35 in **Figure 3** for men and **Figure 4** for women. For a given level of accelerometer-measured  
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37 physical activity, the older participants (over age 55) had a slightly lower BMI but a higher  
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39 body fat percent compared to their younger counterparts. For women, there was heterogeneity  
40  
41 by age in the association between self-reported physical activity and body fat percent  
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43 ( $P=0.03$ ) but there was no heterogeneity by age when physical activity was measured by  
44  
45 accelerometer ( $P=0.27$ ).  
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## 49 DISCUSSION

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52 In this large cross-sectional study of nearly 80,000 participants, we found that associations  
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54 between physical activity and BMI, body fat percent, and waist circumference were stronger  
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56 when physical activity was measured by accelerometer compared to questionnaire self-  
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58 reports. Body fat percent measured by DXA at follow-up showed a slightly stronger  
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3 association with physical activity compared to body fat percent measured by bioelectrical  
4 impedance at baseline, but the overall pattern of association was similar. The correlation  
5 between accelerometer-measured and self-reported physical activity, recorded 5.5 years apart,  
6 was lower in participants with higher BMI and in older participants.  
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13 There was a consistent dose-response relationship between physical activity and adiposity  
14 across the different measures of adiposity, which are highly correlated (14). Our analyses  
15 based on accelerometer-measured physical activity suggest an approximately linear inverse  
16 association between physical activity and adiposity, with the most active participants having  
17 the lowest BMI, body fat percent, and waist circumference. In contrast, the analyses in the  
18 same participants based on self-reported physical activity suggest a comparatively small  
19 further benefit of physical activity greater than 50 MET-hours a week on adiposity.  
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30 We have previously suggested that the steeper inverse association between physical  
31 activity and adiposity within the lower range of physical activity could be due to either a  
32 comparatively larger benefit of physical activity for those who are relatively inactive or  
33 measurement error from over-reporting of high physical activity (14). The present analyses  
34 demonstrating an approximately linear dose-response relationship between accelerometer-  
35 measured physical activity and adiposity supports the latter explanation and further suggests  
36 that over-reporting of total physical activity contributed to the low overall correlation  
37 between self-reported and accelerometer-measured physical activity, although the time lag  
38 between these two measurements of physical activity may have also contributed to a low  
39 overall correlation coefficient. Wrist accelerometer-measured physical activity also has  
40 limitations, such as measuring movement of only one part of the body and the inability to  
41 reliably capture activities such as cycling (7), it has the major advantage of eliminating both  
42 inaccurate reporting that leads to random error as well as reporting bias that may vary by  
43 sociodemographic characteristics.  
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3 Measurement error in the self-reported data results in misclassification of individuals by  
4 physical activity status. We used the IPAQ short form data processing rules since the UK  
5 Biobank questionnaire did not comprehensively cover domain-specific activities, but it is still  
6 likely that lower intensity activities were underreported and reported less accurately (15). In  
7 contrast, the accelerometers were worn for 24 hours a day, over 7 days. Therefore, the lower  
8 correlation between self-reported and accelerometer-measured physical activity in older  
9 participants (16) and the heterogeneity by age seen only with the self-reported data may be  
10 explained by the observation that, in older adults, a greater proportion of physical activity is  
11 of lower intensity (17).  
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25 Individuals with higher body fat percent may report moderate and strenuous physical  
26 activity less accurately than leaner individuals, based on comparisons between self-reported  
27 physical activity and energy expenditure estimated from whole-room indirect calorimeter  
28 (18). In agreement with some previous studies, we found that the correlation between  
29 physical activity measured by questionnaire and accelerometer-measured physical activity  
30 was greater for those with lower BMI (7). This suggests that measurement error of self-  
31 reported physical activity may be greater in overweight and obese BMI groups.  
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42 We, like several prior studies, found stronger associations between accelerometer-  
43 measured physical activity and all measures of adiposity in women compared to men (19–  
44 21). This may partly be due to the fact that, in the present study, men were on average  
45 objectively less physically active than women. Differences in fat metabolism may also play a  
46 role, with a greater proportion of energy derived from lipolysis during exercise in women  
47 compared to men (21, 22).  
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56 To our knowledge, the present study is the largest to date comparing accelerometer-  
57 measured and self-reported physical activity in relation to direct measures of body fat,  
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3 although our results are consistent with prior, smaller studies that suggest a stronger  
4 association between adiposity and accelerometer-measured compared to self-reported  
5 physical activity (18, 20, 23–26). This study was population-based and recruited from 22  
6 regions throughout the UK (27). A major strength of this study is the availability of both  
7 accelerometer-measured physical activity and body fat by impedance in nearly 80,000  
8 participants, together with data on body fat assessed by DXA in over 2,400 participants.  
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10 Additionally, the accelerometers used in this study were waterproof (12), overcoming a  
11 limitation of prior studies where the devices had to be removed for water-based activities  
12 (21).  
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25 While self-reported physical activity was available at baseline in these data,  
26 accelerometer-measured physical activity was assessed only 3-5 years after end of  
27 recruitment, which raises the question of whether higher adiposity at baseline predicts lower  
28 physical activity levels (28) rather than physical activity determining adiposity. However, our  
29 analysis of accelerometer-measured physical activity in relation to DXA-measured body fat  
30 percent, which was assessed within the same time frame as accelerometer-measured physical  
31 activity, showed similar results to the main analysis based on body fat percent assessed by  
32 impedance at baseline. The accelerometer-measured physical activity variable available in  
33 UK Biobank at the time of these analyses cannot be directly compared to MET hours of self-  
34 reported physical activity. However, Willetts et al. have recently developed physical activity  
35 phenotypes using a machine learning model with reference behaviors provided by data from a  
36 subset of participants who wore a camera along with the accelerometer (29). Once these  
37 variables are made publicly available in UK Biobank, research using these metrics will  
38 facilitate the translation of study results into public health messages.  
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57 Other limitations include the lack of data on total energy intake for the whole cohort.  
58 Although accelerometer-determined physical activity is positively associated with percent of  
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3 lean muscle mass (30), we did not consider this as a confounder in these analyses since we  
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5 utilized data on direct measures of body fat percent. Since accelerometer-measured time  
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7 spent in sedentary activity was not available, we did not conduct analyses on sedentary  
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9 activity. Due to the cross-sectional nature of this study, we cannot assess to what extent  
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11 physical activity is causally related to adiposity. Highly active individuals may also be more  
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13 likely to maintain appropriate target dietary energy intake, for example. Although the UK  
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15 Biobank cohort is not representative of the general population in the UK, results of  
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17 associations between exposures and health outcomes may be generalizable and would not  
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19 necessarily require the study population to be representative if the biological basis of the  
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21 exposure-disease relationship is shared.  
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27 In conclusion, our findings based on objective accelerometer data indicate a stronger  
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29 relationship between physical activity and adiposity than previously thought. Comparison of  
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31 estimates of physical activity measured by questionnaire and by accelerometer suggest  
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33 measurement error in self-reported physical activity, emphasizing the need to incorporate  
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35 objective measures of physical activity in future studies.  
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51 **Contributors:** WG, TJK, and GKR were responsible for study concept, design of the study,  
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53 interpretation of the data, and manuscript writing. WG had primary responsibility for  
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55 statistical analysis and final content. All authors reviewed and approved the final manuscript.  
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59 **Dating sharing statement:** No additional data are available.  
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For peer review only

## Figure legends

**Figure 1.** Association of self-reported and accelerometer-measured physical activity with adiposity variables in UK Biobank

Association of A) accelerometer-measured and B) self-reported physical activity with BMI

Association of C) accelerometer-measured and D) self-reported physical activity with body fat percent

Association of E) accelerometer-measured and F) self-reported physical activity with waist circumference

Physical activity was grouped into tenths, separately in men and women.

Adjusted geometric means (from linear regression models) for BMI, body fat percent, and waist circumference are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by squares for men and triangles for women.

These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use.

The figure shows point estimates and 95% confidence intervals.

Abbreviations: BMI, body mass index; MET, metabolic equivalent

**Figure 2.** Association of accelerometer-measured physical activity with body fat percent measured by impedance and DXA in UK Biobank A) men (n=1,185) and B) women (n=1,272)

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3 Physical activity was grouped into fifths, separately in men and women.  
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6 Adjusted geometric means (from linear regression models) for body fat percent are plotted  
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8 against the median value within each fifth of accelerometer-measured physical activity.  
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10 Adjusted geometric means are represented by diamonds for body fat percent measured by  
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12 impedance and circles for body fat percent measured by DXA.  
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16 These analyses are restricted to participants with measures of body fat percent by both  
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18 impedance and DXA. Analyses are stratified by age at recruitment, region of recruitment, and  
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20 socioeconomic status, and are adjusted for educational qualifications, employment status,  
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22 smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted  
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24 for parity and hormone replacement therapy use.  
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28 The figure shows point estimates and 95% confidence intervals.  
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31 Abbreviations: DXA, dual-energy X-ray absorptiometry  
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38 **Figure 3.** Association of self-reported and accelerometer-measured physical activity with  
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40 adiposity variables by age group in UK Biobank men  
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43 Association of physical activity measured by A) accelerometer and B) self-reported  
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45 questionnaire with BMI.  
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49 Association of physical activity measured by C) accelerometer and D) self-reported  
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51 questionnaire with body fat percent.  
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54 Physical activity was grouped into tenths.  
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57 Adjusted geometric means (from linear regression models) for BMI and body fat percent are  
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59 plotted against the median value within each tenth of self-reported or accelerometer-  
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3 measured physical activity. Adjusted geometric means are represented by diamonds for those  
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5 under age 55 and squares for those ages 55 or older.  
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9 These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic  
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11 status, and are adjusted for educational qualifications, employment status, smoking status,  
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13 and alcohol intake frequency.  
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17 The figure shows point estimates and 95% confidence intervals.  
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20 Abbreviations: BMI, body mass index; MET, metabolic equivalent  
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26 **Figure 4.** Association of self-reported and accelerometer-measured physical activity with  
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28 adiposity variables by age group in UK Biobank women  
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31 Association of physical activity measured by A) accelerometer and B) self-reported  
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33 questionnaire with BMI.  
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37 Association of physical activity measured by C) accelerometer and D) self-reported  
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39 questionnaire with body fat percent.  
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43 Physical activity was grouped into tenths.  
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46 Adjusted geometric means (from linear regression models) for BMI and body fat percent are  
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48 plotted against the median value within each tenth of self-reported or accelerometer-  
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50 measured physical activity. Adjusted geometric means are represented by diamonds for those  
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52 under age 55 and squares for those ages 55 or older.  
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56 These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic  
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58 status, and are adjusted for educational qualifications, employment status, smoking status,  
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60 and alcohol intake frequency, parity, and hormone replacement therapy use.

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3 The figure shows point estimates and 95% confidence intervals.  
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6 Abbreviations: BMI, body mass index; MET, metabolic equivalent  
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12 **Supplementary Figure 1.** Flowchart illustrating the application of exclusion criteria for the  
13 current study in UK Biobank  
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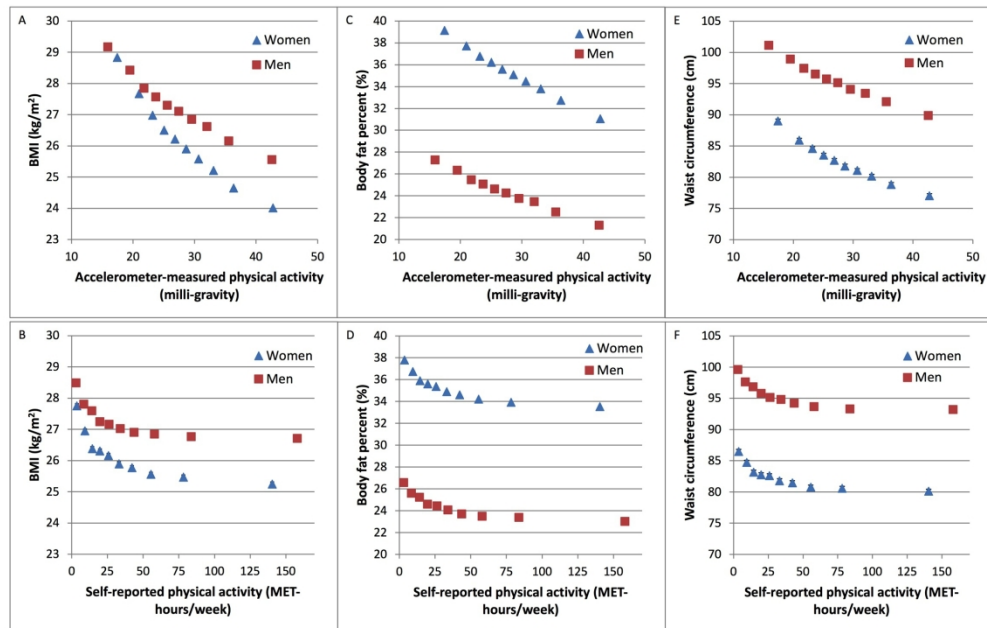


Figure 1. Association of self-reported and accelerometer-measured physical activity with adiposity variables in UK Biobank. Association of A) accelerometer-measured and B) self-reported physical activity with BMI. Association of C) accelerometer-measured and D) self-reported physical activity with body fat percent. Association of E) accelerometer-measured and F) self-reported physical activity with waist circumference. Physical activity was grouped into tenths, separately in men and women. Adjusted geometric means (from linear regression models) for BMI, body fat percent, and waist circumference are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by squares for men and triangles for women. These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use. The figure shows point estimates and 95% confidence intervals. Abbreviations: BMI, body mass index; MET, metabolic equivalent

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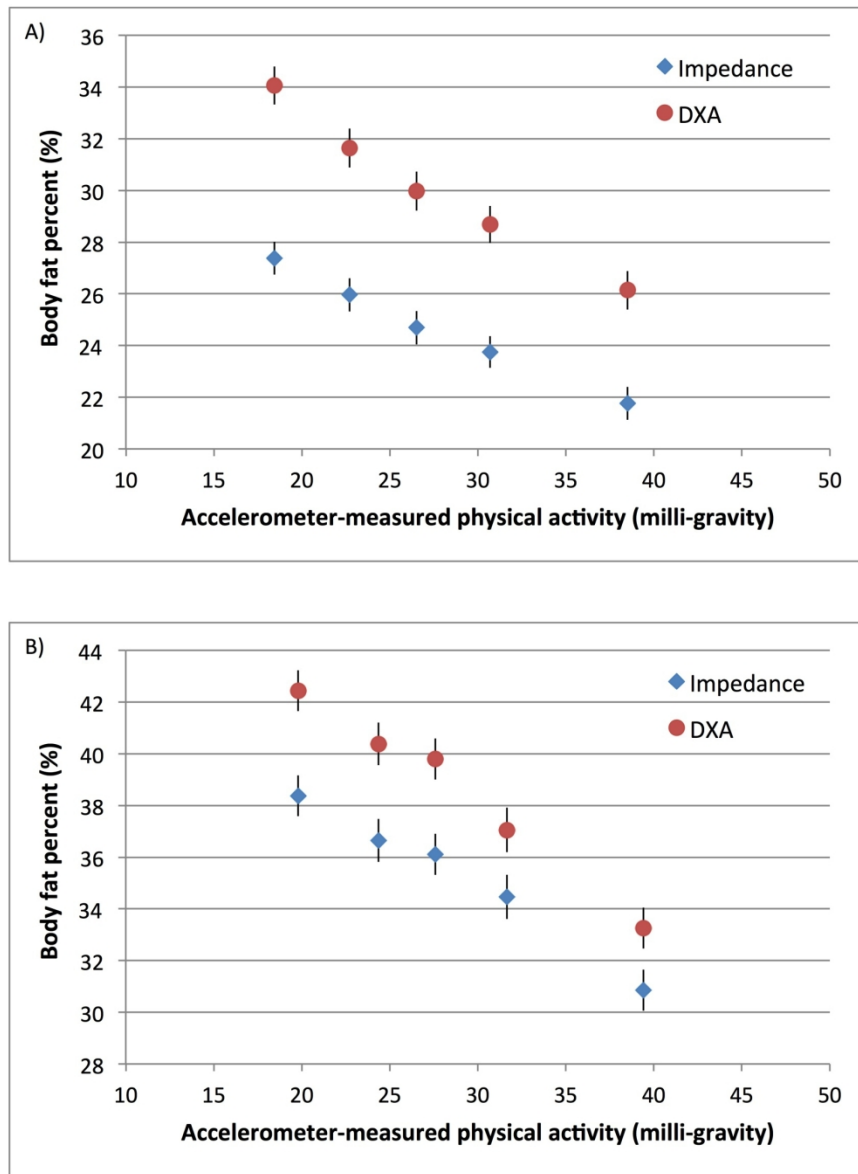


Figure 2. Association of accelerometer-measured physical activity with body fat percent measured by impedance and DXA in UK Biobank A) men (n=1,185) and B) women (n=1,272) Physical activity was grouped into fifths, separately in men and women. Adjusted geometric means (from linear regression models) for body fat percent are plotted against the median value within each fifth of accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for body fat percent measured by impedance and circles for body fat percent measured by DXA. These analyses are restricted to participants with measures of body fat percent by both impedance and DXA. Analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. Analyses in women are additionally adjusted for parity and hormone replacement therapy use. The figure shows point estimates and 95% confidence intervals. Abbreviations: DXA, dual-energy X-ray absorptiometry

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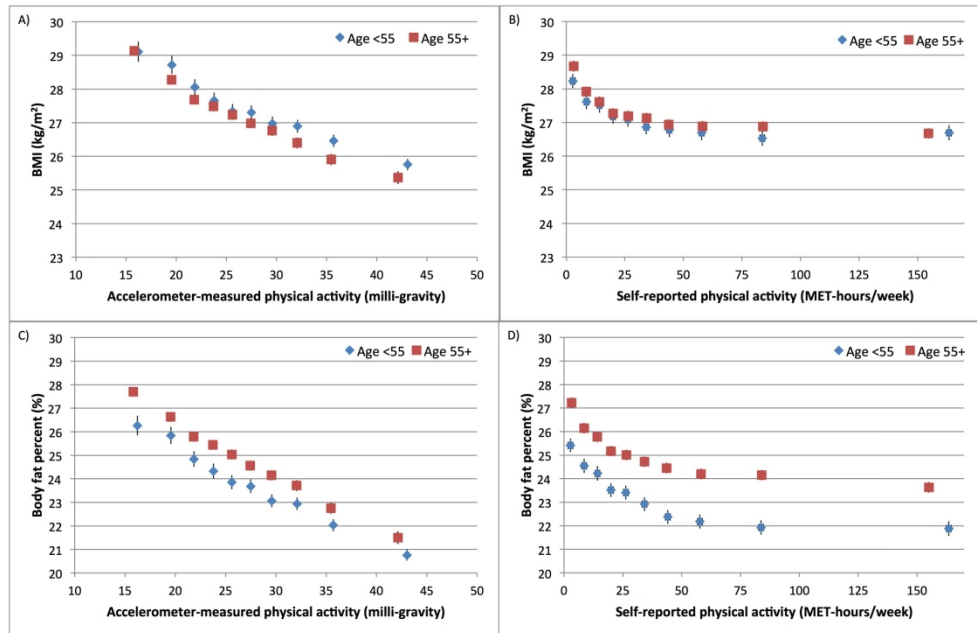


Figure 3. Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank men. Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI. Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent. Physical activity was grouped into tenths. Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for those under age 55 and squares for those ages 55 or older. These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency. The figure shows point estimates and 95% confidence intervals. Abbreviations: BMI, body mass index; MET, metabolic equivalent

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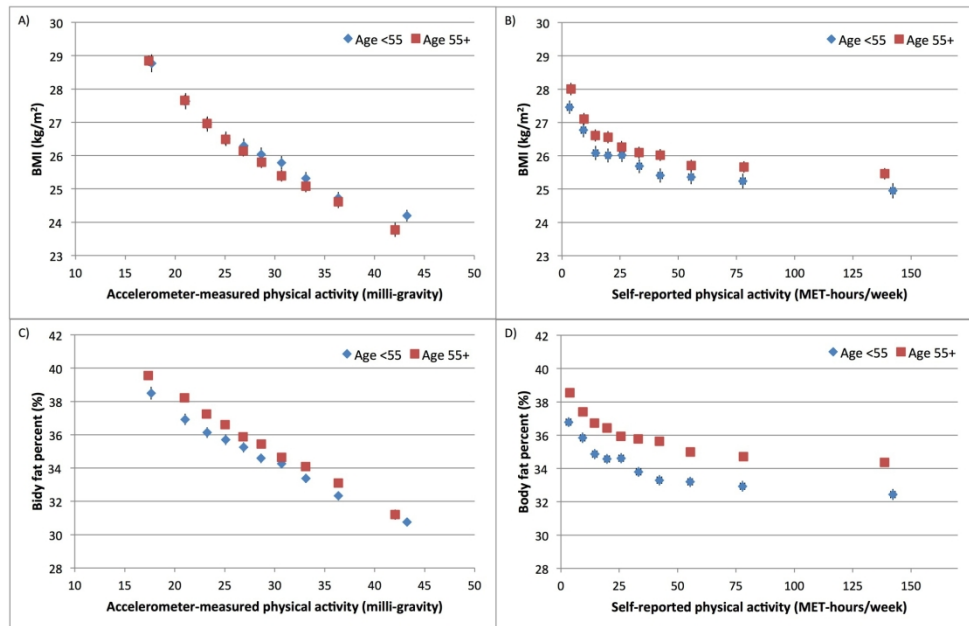
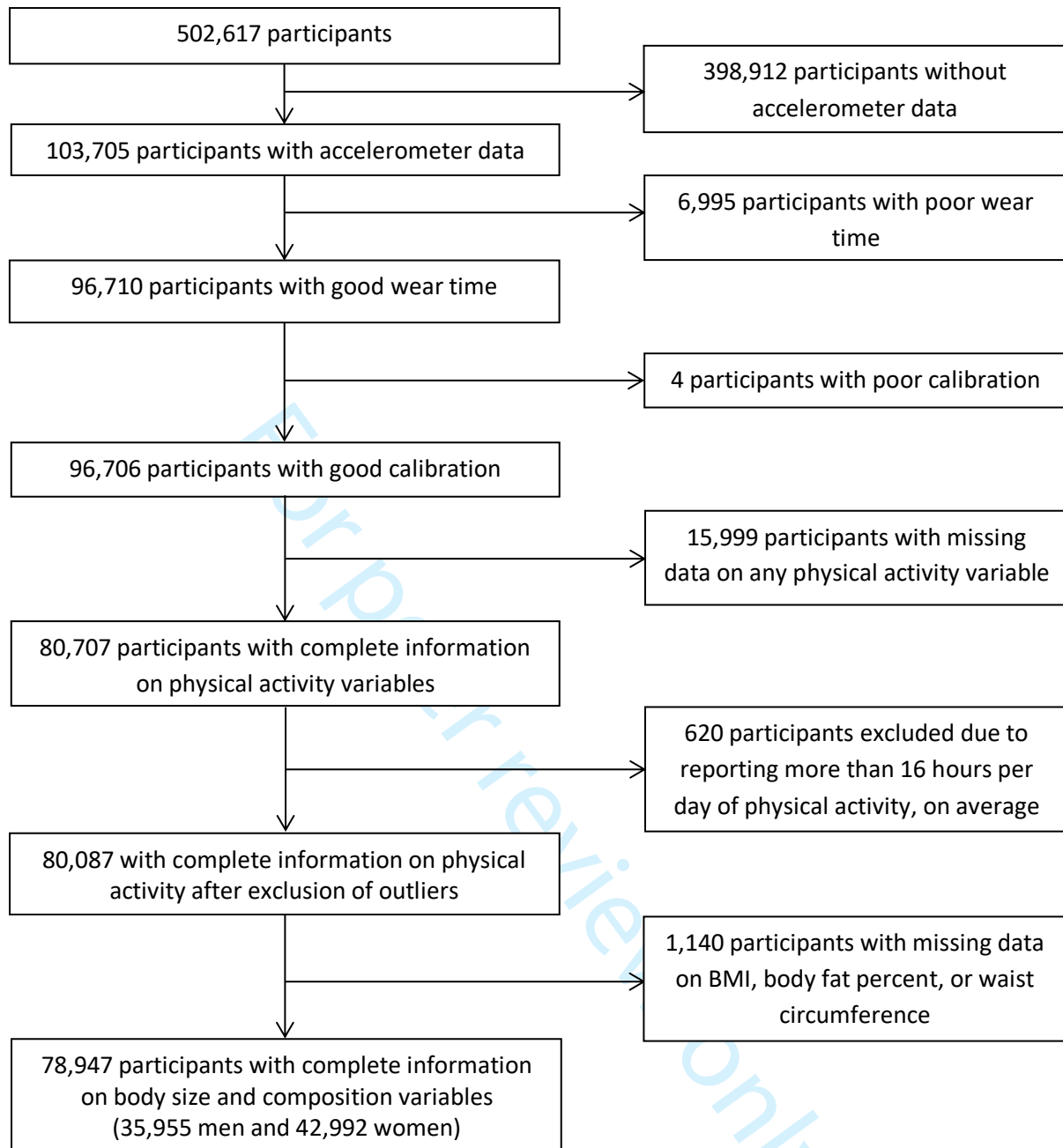


Figure 4. Association of self-reported and accelerometer-measured physical activity with adiposity variables by age group in UK Biobank women. Association of physical activity measured by A) accelerometer and B) self-reported questionnaire with BMI. Association of physical activity measured by C) accelerometer and D) self-reported questionnaire with body fat percent. Physical activity was grouped into tenths. Adjusted geometric means (from linear regression models) for BMI and body fat percent are plotted against the median value within each tenth of self-reported or accelerometer-measured physical activity. Adjusted geometric means are represented by diamonds for those under age 55 and squares for those ages 55 or older. These analyses are stratified by age at recruitment, region of recruitment, and socioeconomic status, and are adjusted for educational qualifications, employment status, smoking status, and alcohol intake frequency, parity, and hormone replacement therapy use. The figure shows point estimates and 95% confidence intervals. Abbreviations: BMI, body mass index; MET, metabolic equivalent

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**Supplementary Table 1. Physical activity questions from the UK Biobank baseline questionnaire**

| Question   | Potential Responses  |
|--|--|
| In a typical WEEK, on how many days did you walk for at least 10 minutes at a time? (Include walking that you do at work, travelling to and from work, and for sport or leisure)                       | Number of days, “Do not know”, “Unable to walk”, or “Prefer not to answer” |
| How many minutes did you usually spend walking on a typical DAY?   | Quantity of minutes, “Do not know”, or “Prefer not to answer”              |
| In a typical WEEK, on how many days did you do 10 minutes or more of moderate physical activities like carrying light loads, cycling at normal pace? (Do not include walking)                          | Number of days, “Do not know”, or “Prefer not to answer”                   |
| How many minutes did you usually spend doing moderate activities on a typical DAY?   | Quantity of minutes, “Do not know”, or “Prefer not to answer”              |
| In a typical WEEK, how many days did you do 10 minutes or more of vigorous physical activity? (These are activities that make you sweat or breathe hard such as fast cycling, aerobics, heavy lifting) | Number of days, “Do not know”, or “Prefer not to answer”                   |
| How many minutes did you usually spend doing vigorous activities on a typical DAY?   | Quantity of minutes, “Do not know”, or “Prefer not to answer”              |

**Supplementary Table 2. Spearman correlation between self-reported physical activity and accelerometer-measured physical activity, according to participant characteristics in UK Biobank men**

|   | <b>N Men (%)</b> | <b>Correlation</b> | <b>95% Confidence Interval</b> |
|---|------------------|--------------------|--------------------------------|
| <b>Total</b>                                | 35,955           | 0.24               | 0.23, 0.25                     |
| <b>Age group at recruitment (years)</b>     |                  |                    |                                |
| <55 years                                   | 13,214 (36.8)    | 0.31               | 0.29, 0.32                     |
| 55+ years                                   | 22,741 (63.3)    | 0.22               | 0.21, 0.23                     |
| <b>Socioeconomic status, fifths</b>         |                  |                    |                                |
| Top fifth                                   | 7,584 (21.1)     | 0.23               | 0.21, 0.25                     |
| Bottom fifth                                | 6,800 (18.9)     | 0.26               | 0.23, 0.28                     |
| <b>BMI (kg/m<sup>2</sup>)</b>               |                  |                    |                                |
| <25   | 10,590 (29.5)    | 0.27               | 0.25, 0.28                     |
| 25-29.9                                     | 17,874 (49.7)    | 0.21               | 0.19, 0.22                     |
| >30   | 7,491 (20.8)     | 0.22               | 0.20, 0.24                     |
| <b>College or university degree</b>         |                  |                    |                                |
| Yes   | 16,709 (46.5)    | 0.25               | 0.24, 0.27                     |
| No  | 19,246 (53.5)    | 0.24               | 0.22, 0.25                     |
| <b>Current employment status</b>            |                  |                    |                                |
| In paid employment or self-employed         | 22,942 (63.8)    | 0.27               | 0.26, 0.28                     |
| Retired                                     | 11,361 (31.6)    | 0.24               | 0.22, 0.26                     |
| Other                                       | 1,652 (4.6)      | 0.30               | 0.26, 0.34                     |
| <b>Job involves mainly walking/standing</b> |                  |                    |                                |
| Never or rarely                             | 9,825 (42.8)     | 0.29               | 0.27, 0.31                     |
| Sometimes                                   | 7,534 (32.9)     | 0.24               | 0.22, 0.26                     |
| Usually or Always                           | 5,574 (24.3)     | 0.19               | 0.16, 0.21                     |
| <b>Job involves heavy manual work</b>       |                  |                    |                                |
| Never, rarely                               | 16,443 (71.7)    | 0.27               | 0.26, 0.29                     |
| Sometimes                                   | 4,160 (18.1)     | 0.17               | 0.14, 0.19                     |
| Usually or Always                           | 2,335 (10.2)     | 0.12               | 0.08, 0.16                     |
| <b>Alcohol intake frequency</b>             |                  |                    |                                |
| Weekly or more                              | 29,421 (81.8)    | 0.23               | 0.22, 0.24                     |
| Less than weekly                            | 6,530 (18.2)     | 0.28               | 0.26, 0.30                     |
| <b>Smoking status</b>                       |                  |                    |                                |
| Never                                       | 18,928 (52.6)    | 0.26               | 0.24, 0.27                     |
| Ever  | 16,964 (47.2)    | 0.22               | 0.21, 0.24                     |
| <b>Long-standing illness or disability</b>  |                  |                    |                                |
| No  | 25,129 (69.9)    | 0.23               | 0.22, 0.24                     |
| Yes   | 10,825 (30.1)    | 0.25               | 0.23, 0.27                     |

**Supplementary Table 3. Spearman correlation between self-reported physical activity and accelerometer-measured physical activity, according to participant characteristics in UK Biobank women**

|   | <b>N Women (%)</b> | <b>Correlation</b> | <b>95% Confidence Interval</b> |
|---|--------------------|--------------------|--------------------------------|
| <b>Total</b>                                | 42,992             | 0.22               | 0.21, 0.23                     |
| <b>Age group at recruitment (years)</b>     |                    |                    |                                |
| <55 years                                   | 18,973 (44.1)      | 0.26               | 0.25, 0.28                     |
| 55+ years                                   | 24,019 (55.9)      | 0.20               | 0.19, 0.22                     |
| <b>Socioeconomic status, fifths</b>         |                    |                    |                                |
| Top fifth                                   | 8,401 (19.5)       | 0.22               | 0.30, 0.24                     |
| Bottom fifth                                | 8,744 (20.3)       | 0.22               | 0.30, 0.24                     |
| <b>BMI (kg/m<sup>2</sup>)</b>               |                    |                    |                                |
| <25   | 20,255 (47.1)      | 0.21               | 0.20, 0.23                     |
| 25-29.9                                     | 15,146 (35.2)      | 0.18               | 0.17, 0.20                     |
| >30   | 7,591 (17.7)       | 0.15               | 0.13, 0.17                     |
| <b>College or university degree</b>         |                    |                    |                                |
| Yes   | 19,214 (44.7)      | 0.22               | 0.21, 0.24                     |
| No  | 23,778 (55.3)      | 0.22               | 0.20, 0.23                     |
| <b>Current employment status</b>            |                    |                    |                                |
| In paid employment or self-employed         | 26,693 (62.1)      | 0.24               | 0.23, 0.25                     |
| Retired                                     | 12,710 (29.6)      | 0.22               | 0.20, 0.24                     |
| Other                                       | 3,589 (8.4)        | 0.30               | 0.27, 0.33                     |
| <b>Job involves mainly walking/standing</b> |                    |                    |                                |
| Never or rarely                             | 12,191 (45.7)      | 0.25               | 0.23, 0.27                     |
| Sometimes                                   | 7,839 (29.4)       | 0.21               | 0.19, 0.23                     |
| Usually or Always                           | 6,648 (24.9)       | 0.18               | 0.16, 0.20                     |
| <b>Job involves heavy manual work</b>       |                    |                    |                                |
| Never, rarely                               | 20,762 (77.8)      | 0.24               | 0.22, 0.25                     |
| Sometimes                                   | 4,353 (16.3)       | 0.17               | 0.14, 0.20                     |
| Usually or Always                           | 1,567 (5.9)        | 0.13               | 0.08, 0.18                     |
| <b>Alcohol intake frequency</b>             |                    |                    |                                |
| Weekly or more                              | 29,829 (69.4)      | 0.22               | 0.21, 0.23                     |
| Less than weekly                            | 13,152 (30.6)      | 0.21               | 0.20, 0.23                     |
| <b>Smoking status</b>                       |                    |                    |                                |
| Never                                       | 25,998 (60.5)      | 0.21               | 0.20, 0.22                     |
| Ever  | 16,936 (39.4)      | 0.23               | 0.22, 0.25                     |
| <b>Long-standing illness or disability</b>  |                    |                    |                                |
| No  | 32,307 (75.2)      | 0.21               | 0.20, 0.22                     |
| Yes   | 10,685 (24.9)      | 0.23               | 0.21, 0.24                     |

Supplementary Table 4. Association of self-reported and accelerometer-measured physical activity with measures of adiposity

|                             | N     | BMI<br>(kg/m <sup>2</sup> ) | 95% CI       | Body fat<br>percent | 95% CI       | Waist<br>circumference<br>(cm) | 95% CI         |
|-----------------------------|-------|-----------------------------|--------------|---------------------|--------------|--------------------------------|----------------|
| <b>Men</b>                  |       |                             |              |                     |              |                                |                |
| <b>Questionnaire</b>        |       |                             |              |                     |              |                                |                |
| Bottom tenth (least active) | 3,643 | 0.00 (reference)            |              | 0.00 (reference)    |              | 0.00 (reference)               |                |
| 2nd tenth                   | 3,742 | -0.69                       | -0.87, -0.52 | -0.99               | -1.23, -0.74 | -1.97                          | -2.45, -1.50   |
| 3rd tenth                   | 3,410 | -0.91                       | -1.09, -0.73 | -1.42               | -1.68, -1.17 | -2.89                          | -3.38, -2.41   |
| 4th tenth                   | 3,677 | -1.22                       | -1.40, -1.05 | -1.97               | -2.22, -1.72 | -3.81                          | -4.29, -3.34   |
| 5th tenth                   | 3,522 | -1.32                       | -1.50, -1.14 | -2.14               | -2.39, -1.88 | -4.47                          | -4.95, -3.99   |
| 6th tenth                   | 3,584 | -1.45                       | -1.63, -1.27 | -2.50               | -2.75, -2.24 | -4.79                          | -5.27, -4.31   |
| 7th tenth                   | 3,596 | -1.59                       | -1.76, -1.41 | -2.88               | -3.13, -2.63 | -5.41                          | -5.89, -4.93   |
| 8th tenth                   | 3,591 | -1.63                       | -1.81, -1.45 | -3.09               | -3.34, -2.83 | -5.92                          | -6.40, -5.44   |
| 9th tenth                   | 3,595 | -1.71                       | -1.89, -1.53 | -3.21               | -3.46, -2.95 | -6.33                          | -6.81, -5.85   |
| Top tenth (most active)     | 3,595 | -1.77                       | -1.95, -1.59 | -3.56               | -3.81, -3.31 | -6.42                          | -6.90, -5.93   |
| <b>Accelerometer</b>        |       |                             |              |                     |              |                                |                |
| Bottom tenth (least active) | 3,598 | 0.00 (reference)            |              | 0.00 (reference)    |              | 0.00 (reference)               |                |
| 2nd tenth                   | 3,604 | -0.77                       | -0.95, -0.60 | -0.99               | -1.24, -0.75 | -2.23                          | -2.70, -1.76   |
| 3rd tenth                   | 3,592 | -1.33                       | -1.50, -1.15 | -1.83               | -2.07, -1.58 | -3.69                          | -4.16, -3.22   |
| 4th tenth                   | 3,610 | -1.60                       | -1.77, -1.42 | -2.20               | -2.45, -1.95 | -4.59                          | -5.06, -4.12   |
| 5th tenth                   | 3,597 | -1.88                       | -2.06, -1.71 | -2.69               | -2.94, -2.44 | -5.43                          | -5.90, -4.96   |
| 6th tenth                   | 3,585 | -2.07                       | -2.24, -1.89 | -3.04               | -3.28, -2.79 | -6.00                          | -6.47, -5.53   |
| 7th tenth                   | 3,589 | -2.32                       | -2.49, -2.14 | -3.52               | -3.77, -3.27 | -7.01                          | -7.49, -6.54   |
| 8th tenth                   | 3,594 | -2.57                       | -2.75, -2.39 | -3.84               | -4.09, -3.59 | -7.69                          | -8.17, -7.22   |
| 9th tenth                   | 3,591 | -3.02                       | -3.20, -2.84 | -4.75               | -5.00, -4.50 | -9.01                          | -9.48, -8.53   |
| Top tenth (most active)     | 3,595 | -3.61                       | -3.79, -3.43 | -5.98               | -6.24, -5.73 | -11.23                         | -11.72, -10.75 |

|                             |       |                  |              |                  |              |                  |                |
|-----------------------------|-------|------------------|--------------|------------------|--------------|------------------|----------------|
|                             |       |                  |              |                  |              |                  |                |
| <b>Women</b>                |       |                  |              |                  |              |                  |                |
| <b>Questionnaire</b>        |       |                  |              |                  |              |                  |                |
| Bottom tenth (least active) | 4,433 | 0.00 (reference) |              | 0.00 (reference) |              | 0.00 (reference) |                |
| 2nd tenth                   | 4,187 | -0.81            | -1.00, -0.61 | -1.05            | -1.33, -0.78 | -1.77            | -2.25, -1.29   |
| 3rd tenth                   | 4,278 | -1.37            | -1.57, -1.18 | -1.89            | -2.16, -1.61 | -3.33            | -3.81, -2.86   |
| 4th tenth                   | 4,318 | -1.44            | -1.64, -1.25 | -2.16            | -2.43, -1.88 | -3.74            | -4.22, -3.27   |
| 5th tenth                   | 4,296 | -1.60            | -1.79, -1.40 | -2.44            | -2.72, -2.17 | -3.92            | -4.39, -3.44   |
| 6th tenth                   | 4,308 | -1.86            | -2.05, -1.66 | -2.89            | -3.16, -2.61 | -4.71            | -5.18, -4.23   |
| 7th tenth                   | 4,276 | -1.98            | -2.18, -1.79 | -3.18            | -3.45, -2.90 | -5.02            | -5.50, -4.55   |
| 8th tenth                   | 4,300 | -2.20            | -2.39, -2.00 | -3.57            | -3.85, -3.30 | -5.73            | -6.20, -5.25   |
| 9th tenth                   | 4,305 | -2.28            | -2.48, -2.09 | -3.86            | -4.14, -3.59 | -5.91            | -6.39, -5.44   |
| Top tenth (most active)     | 4,291 | -2.51            | -2.70, -2.31 | -4.25            | -4.52, -3.97 | -6.39            | -6.87, -5.91   |
| <b>Accelerometer</b>        |       |                  |              |                  |              |                  |                |
| Bottom tenth (least active) | 4,314 | 0.00 (reference) |              | 0.00 (reference) |              | 0.00 (reference) |                |
| 2nd tenth                   | 4,292 | -1.14            | -1.33, -0.95 | -1.43            | -1.70, -1.16 | -3.02            | -3.49, -2.56   |
| 3rd tenth                   | 4,293 | -1.84            | -2.03, -1.65 | -2.35            | -2.62, -2.09 | -4.42            | -4.89, -3.95   |
| 4th tenth                   | 4,307 | -2.31            | -2.50, -2.12 | -2.90            | -3.17, -2.63 | -5.43            | -5.90, -4.97   |
| 5th tenth                   | 4,312 | -2.60            | -2.79, -2.41 | -3.52            | -3.79, -3.25 | -6.27            | -6.74, -5.80   |
| 6th tenth                   | 4,286 | -2.92            | -3.11, -2.72 | -4.05            | -4.32, -3.79 | -7.18            | -7.65, -6.71   |
| 7th tenth                   | 4,292 | -3.22            | -3.42, -3.04 | -4.63            | -4.90, -4.36 | -7.88            | -8.35, -7.41   |
| 8th tenth                   | 4,301 | -3.60            | -3.80, -3.41 | -5.34            | -5.61, -5.07 | -8.80            | -9.27, -8.33   |
| 9th tenth                   | 4,305 | -4.17            | -4.36, -3.98 | -6.37            | -6.64, -6.10 | -10.12           | -10.59, -9.64  |
| Top tenth (most active)     | 4,290 | -4.80            | -4.99, -4.60 | -8.06            | -8.33, -7.78 | -11.92           | -12.39, -11.44 |

Analyses are adjusted for age, socioeconomic status, alcohol intake, smoking status, educational qualifications, and employment status. Analyses are further adjusted for parity and hormone replacement therapy use in women.



**Supplementary Table 5. Association of accelerometer-measured physical activity with body fat percent, measured by bioelectrical impedance and dual energy X-ray absorptiometry (DXA) in UK Biobank**

| Accelerometer-measured physical activity | N   | Mean body fat percent | 95% CI     | Coefficient            | 95% CI       |
|--|-----|-----------------------|------------|------------------------|--------------|
| <b>Men</b>                               |     |                       |            |                        |              |
| <b>Measured by impedance</b>             |     |                       |            |                        |              |
| Bottom fifth (least active)              | 237 | 27.4                  | 26.7, 28.0 | 0.00 (reference group) |              |
| 2nd fifth                                | 231 | 26.0                  | 25.3, 26.6 | -1.29                  | -2.21, -0.38 |
| 3rd fifth                                | 229 | 24.7                  | 24.0, 25.3 | -2.63                  | -3.55, -1.71 |
| 4th fifth                                | 253 | 23.8                  | 23.1, 24.4 | -3.46                  | -4.36, -2.56 |
| Top fifth (most active)                  | 235 | 21.8                  | 21.1, 22.4 | -5.51                  | -6.45, -4.58 |
| <b>Men</b>                               |     |                       |            |                        |              |
| <b>Measured by DXA</b>                   |     |                       |            |                        |              |
| Bottom fifth (least active)              | 237 | 34.1                  | 33.3, 34.8 | 0.00 (reference group) |              |
| 2nd fifth                                | 231 | 31.6                  | 30.9, 32.4 | -2.38                  | -3.45, -1.31 |
| 3rd fifth                                | 229 | 30.0                  | 29.2, 30.7 | -4.12                  | -5.20, -3.05 |
| 4th fifth                                | 253 | 28.7                  | 28.0, 29.4 | -5.48                  | -6.54, -4.42 |
| Top fifth (most active)                  | 235 | 26.1                  | 25.4, 26.9 | -8.18                  | -9.27, -7.08 |
| <b>Women</b>                             |     |                       |            |                        |              |
| <b>Measured by impedance</b>             |     |                       |            |                        |              |
| Bottom fifth (least active)              | 270 | 38.4                  | 37.6, 39.1 | 0.00 (reference group) |              |
| 2nd fifth                                | 244 | 36.6                  | 35.9, 37.4 | -1.46                  | -2.55, -0.37 |
| 3rd fifth                                | 265 | 36.1                  | 35.4, 36.9 | -1.93                  | -3.01, -0.85 |
| 4th fifth                                | 228 | 34.5                  | 33.7, 35.3 | -3.43                  | -4.55, -2.31 |
| Top fifth (most active)                  | 265 | 30.8                  | 30.1, 31.6 | -6.97                  | -8.07, -5.87 |
| <b>Women</b>                             |     |                       |            |                        |              |
| <b>Measured by DXA</b>                   |     |                       |            |                        |              |
| Bottom fifth (least active)              | 270 | 42.5                  | 41.7, 43.3 | 0.00 (reference group) |              |
| 2nd fifth                                | 244 | 40.4                  | 39.6, 41.2 | -1.87                  | -3.04, -0.71 |
| 3rd fifth                                | 265 | 39.8                  | 39.0, 40.6 | -2.55                  | -3.70, -1.40 |
| 4th fifth                                | 228 | 37.1                  | 36.2, 37.9 | -4.98                  | -6.17, -3.78 |
| Top fifth (most active)                  | 265 | 33.3                  | 32.5, 34.1 | -8.83                  | -10.0, -7.65 |

Analyses are adjusted for age, socioeconomic status, alcohol intake, smoking status, educational qualifications, and employment status. Analyses are further adjusted for parity and hormone replacement therapy use in women.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   |
|------------------------------|---------|--|
| <b>Title and abstract</b>    | 1       | <input checked="" type="checkbox"/> (a) Indicate the study's design with a commonly used term in the title or the abstract <a href="#">pages 1-2</a><br><input checked="" type="checkbox"/> (b) Provide in the abstract an informative and balanced summary of what was done and what was found <a href="#">pages 2-3</a>  |
| <b>Introduction</b>          |         |  |
| Background/rationale         | 2       | <input checked="" type="checkbox"/> Explain the scientific background and rationale for the investigation being reported <a href="#">page 4</a>  |
| Objectives                   | 3       | <input checked="" type="checkbox"/> State specific objectives, including any prespecified hypotheses <a href="#">page 4</a>  |
| <b>Methods</b>               |         |  |
| Study design                 | 4       | <input checked="" type="checkbox"/> Present key elements of study design early in the paper <a href="#">pages 5-9</a>  |
| Setting                      | 5       | <input checked="" type="checkbox"/> Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection <a href="#">pages 5-7</a>  |
| Participants                 | 6       | <input checked="" type="checkbox"/> (a) Give the eligibility criteria, and the sources and methods of selection of participants <a href="#">pages 5-6</a>  |
| Variables                    | 7       | <input checked="" type="checkbox"/> Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable <a href="#">pages 6-8</a>   |
| Data sources/<br>measurement | 8*      | <input checked="" type="checkbox"/> 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 <a href="#">pages 6-7</a>   |
| Bias                         | 9       | <input checked="" type="checkbox"/> Describe any efforts to address potential sources of bias <a href="#">page 4</a>   |
| Study size                   | 10      | <input checked="" type="checkbox"/> Explain how the study size was arrived at <a href="#">pages 5-6</a>  |
| Quantitative variables       | 11      | <input checked="" type="checkbox"/> Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why <a href="#">pages 6-8</a>   |
| Statistical methods          | 12      | <input checked="" type="checkbox"/> (a) Describe all statistical methods, including those used to control for confounding <a href="#">pages 7-9</a><br><input checked="" type="checkbox"/> (b) Describe any methods used to examine subgroups and interactions <a href="#">pages 8-9</a><br><input checked="" type="checkbox"/> (c) Explain how missing data were addressed <a href="#">pages 8-9</a><br>N/A (d) If applicable, describe analytical methods taking account of sampling strategy<br><input checked="" type="checkbox"/> (e) Describe any sensitivity analyses <a href="#">pages 8-9</a> |
| <b>Results</b>               |         |  |
| Participants                 | 13*     | <input checked="" type="checkbox"/> (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 <a href="#">page 9 and Supplementary Figure 1</a><br><input checked="" type="checkbox"/> (b) Give reasons for non-participation at each stage <a href="#">Supplementary Figure 1</a><br><input checked="" type="checkbox"/> (c) Consider use of a flow diagram <a href="#">Supplementary Figure 1</a>  |
| Descriptive data             | 14*     | <input checked="" type="checkbox"/> (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders <a href="#">pages 9-10</a><br><input checked="" type="checkbox"/> (b) Indicate number of participants with missing data for each variable of interest <a href="#">pages 5-6, Supplementary Figure 1</a>   |
| Outcome data                 | 15*     | <input checked="" type="checkbox"/> Report numbers of outcome events or summary measures <a href="#">pages 10-12, figures</a>  |
| Main results                 | 16      | <input checked="" type="checkbox"/> (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 <a href="#">page 8, figures, supplementary tables,</a>  |

|                          |    |  |
|--------------------------|----|--|
|                          |    | <a href="#">22-24 (figure legends)</a>   |
|                          |    | <input checked="" type="checkbox"/> (b) Report category boundaries when continuous variables were categorized <a href="#">page 9</a>   |
|                          |    | N/A (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   |
| Other analyses           | 17 | <input checked="" type="checkbox"/> Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses <a href="#">pages 11-12</a>   |
| <b>Discussion</b>        |    |  |
| Key results              | 18 | <input checked="" type="checkbox"/> Summarise key results with reference to study objectives <a href="#">pages 12-13</a>   |
| Limitations              | 19 | <input checked="" type="checkbox"/> Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias <a href="#">pages 15-16</a>                 |
| Interpretation           | 20 | <input checked="" type="checkbox"/> Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence <a href="#">pages 13-16</a> |
| Generalisability         | 21 | <input checked="" type="checkbox"/> Discuss the generalisability (external validity) of the study results <a href="#">page 16</a>  |
| <b>Other information</b> |    |  |
| Funding                  | 22 | <input checked="" type="checkbox"/> 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 <a href="#">page 16</a>                  |

\*Give information separately for exposed and unexposed groups.

**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](http://www.strobe-statement.org).