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Association between grip strength and diabetes prevalence in black, South Asian, and white European ethnic groups: a cross-sectional study of 418,656 UK Biobank participants

Running Head: Grip strength and diabetes in black, South Asian, and white adults

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Novelty statement

- In UK Biobank, grip strength was significantly associated with odds of diabetes, independent of major confounding factors in all ethnic groups.
- Grip strength was lower (by ~5-6 kg) in South Asian men and women compared to black and white European adults.
- Lower grip strength combined with higher diabetes prevalence resulted in the attributable risk for diabetes associated with low grip strength being substantially higher in South Asians (3.9 and 4.2 cases per 100 men and women) than in whites (2.0 and 0.6 cases). Attributable risk was also high in black men (4.3 cases) but not in black women (0.4 cases).

Abstract

Aims: Diabetes prevalence is substantially higher in black and south Asian compared with white European adults. This study aimed to quantify the extent to which ethnic differences in muscular strength might account for this.

Methods: This cross-sectional study used baseline data from UK Biobank on 418,656 white European, black and south Asian adults, aged 40-69 years, who had complete data on diabetes status and hand-grip strength. Associations between handgrip strength and diabetes were assessed using logistic regression and adjusted for potential confounding factors.

Results: Lower grip strength was associated with higher prevalence of diabetes, independent of confounding factors, across all ethnicities in both men and women. Diabetes prevalence was ~3-4 fold higher in South Asians and ~2-3 fold higher in black adults compared to white Europeans across all levels of grip strength, but grip strength in South Asian men and women was ~5-6 kg lower than the other ethnic groups. Thus, the attributable risk for diabetes associated with low grip strength was substantially higher in south Asians (3.9 and 4.2 cases per 100 men and women) than in whites (2.0 and 0.6 cases). Attributable risk associated with low grip strength was also high in black men (4.3 cases) but not in black women (0.4 cases).

Conclusions: Low strength is associated with a disproportionately large number of diabetes cases in south Asian adults and black men. Trials are needed to determine whether interventions to improve strength in these groups could help reduce ethnic inequalities in diabetes prevalence.

Introduction

Type 2 diabetes is a major public health problem, accounting for 10% of healthcare expenditure and almost 400 million cases globally [1]. In Westernised countries, diabetes prevalence is more than double in black [2;3] and 3-4 fold higher in south Asian adults [3;4] compared with white European populations, and worldwide diabetes prevalence is increasing faster in Asian and African countries than in Europe and high-income English speaking countries [5].

There is evidence that strength could be an important risk factor for diabetes. Low hand grip strength has been predictive of incident diabetes in prospective cohort studies of Australian men of predominantly white European origin [6] and Japanese-American adults [7]. In addition Canadian [8] and Japanese [9] studies have reported associations between indices of musculoskeletal fitness and diabetes risk. There is also evidence that participation in muscle strengthening exercise affects risk of type 2 diabetes, independent of participation in aerobic physical activity [10;11]. However, the evidence is not unequivocal with the Prospective Urban-Rural Epidemiology (PURE) Study undertaken across 17 countries reporting no significant association between grip strength and diabetes, although a clear trend was evident [12]. Muscular strength may vary by ethnicity [12-14]. However, it is unclear whether the association between muscular strength and diabetes risk also varies according to ethnicity and whether this may contribute to the ethnic differences in diabetes prevalence.

The purpose of this study was therefore to determine the associations between muscular strength and diabetes risk in white European, black and south Asian men and women in UK Biobank to determine a) whether the magnitude of these relationships was similar across ethnic groups and b) to quantify the extent to which ethnic differences in diabetes prevalence may be associated with ethnic differences in strength.

Methods

Study Population

This cross-sectional study used baseline data from UK Biobank: a large, population-based cohort study set up to study the lifestyle, environmental, and genetic determinants of a range of important diseases of adulthood [15]. Between April 2007 and December 2010, UK Biobank recruited 502 682 participants (5.5% response rate) aged 40-69 years, at 22 assessment centres across the UK [15]. Extensive baseline information was collected via questionnaires and physical measurements [15].

UK Biobank received ethical approval from the North West Multi-centre Research Ethics Committee (REC reference: 11/NW/03820). All participants gave written informed consent before enrolment in the study, which was conducted in accord with principles of the Declaration of Helsinki.

Definitions and Inclusion Criteria

We included the 418,656 white European, black and south Asian participants with no history of heart disease (angina, heart attack and stroke (28,813 cases with heart disease were excluded)) or cancer (38,412 cases were excluded), who had complete data on diabetes status and hand grip strength. These exclusions resulted in exclusion of 2268 diabetes cases from participants with cancer and 4997 diabetes cases from participants with heart disease; the final sample included 18,711 diabetes cases. Presence of diabetes (excluding gestational), heart disease and cancer was determined from self-report of a physician diagnosis. Ethnicity was based on self-classification into the 19 UK Office of National Statistics groups. This study was restricted to participants who identified themselves as: white (British, Irish and other white European), south Asian (Indian, Pakistani and Bangladeshi) and black (black-African, black-Caribbean and other black).

Muscular strength

Muscular strength was assessed using hand-grip strength, measured using a Jamar J00105 hydraulic hand dynamometer. Isometric grip force was assessed from a single 3-second maximal grip effort of the right and left arms with the participant seated upright with their elbow by their side and flexed at 90º so that their forearm was facing forwards and resting on an armrest. The mean of the right and left values, expressed in absolute units (kg), and relative to bodyweight (kg per kg bodyweight), was used in the analysis, as reported elsewhere [16;17].

Physical activity

Physical activity was assessed by a self-report questionnaire, based on the IPAQ short form, with participants reporting frequency and duration of walking, moderate and vigorous activity undertaken in a typical week. Data were analysed in accordance with the International Physical Activity Questionnaire (IPAQ) scoring protocol (http://www.ipaq.ki.se/scoring.pdf), and total physical activity was computed as the sum of walking, moderate and vigorous activity, measured as metabolic equivalents (MET-hours/week). Participants were excluded from the analyses if they recorded implausible values; defined as the sum of their total physical activity, sleeping time and TV-viewing exceeding 24 hours.

Adiposity measurements

Anthropometric measurements were obtained by trained clinic staff using standard operating procedures and regularly calibrated equipment. Weight, percentage body fat and fat-free mass (by bio-impedance) were measured using standard operating procedures, without shoes and outdoor clothing, using the Tanita BC 418MA body composition analyser. Height was measured, without shoes, using the wall-mounted SECA 240 height measure. BMI was calculated as body mass (kg) divided by the square of height (metres).

Assessment of covariates

Potential confounders were identified *a priori* based on established relationships with diabetes and muscular strength or both. Area-based socioeconomic status was derived from postcode of residence, using the Townsend score which is derived from Census data on housing, employment, social class and car availability. Age was calculated from dates of birth and baseline assessment. Smoking status was categorised into never, former and current smoking. Dietary information was collected via a self-reported dietary questionnaire, with participants asked how many portions of specified foods they generally ate. Medical history (physician diagnosis of long-standing illness, depression, stroke, angina, myocardial infarction, hypertension, cancer and diabetes) was collected from the self-completed, baseline assessment questionnaire. Further details of these measurements can be found in the UK Biobank online protocol (http://www.ukbiobank.ac.uk).

Statistical analyses

Descriptive statistics were derived for ethnicity sub-groups. Continuous variables were summarised using the median and inter-quartile range, and categorical using frequencies and percentages. The distribution of grip strength in men and women in each ethnic group was plotted.

Multivariate binary logistic regression models were used to examine associations between grip strength (expressed in absolute units (per SD difference and per 5 kg difference), and relative to body weight (per SD difference and per 0.05 kg/kg bodyweight difference)) with diabetes within each ethnic group. Models were run initially adjusting for age, education, number of years with diabetes and socioeconomic status (Model 1), then after adding percentage body fat, smoking, dietary intake (fruit and vegetables, alcohol, processed meat, red meat, oily fish), sleep duration and physical activity as an additional covariates (Model 2). Attributable risk (i.e. the number of excess cases that would be avoided if the risk factor was removed) associated with low grip strength (i.e. grip strength below the age- and sex-specific overall UK Biobank population median (threshold values shown in Supplementary Table 1) expressed in kg was calculated for each ethnicity and sex group(threshold values shown in Supplementary Table 1). In sensitivity analysis we repeated the attributable risk calculations using the 33rd centile (i.e. lowest tertile) and the 67th centile (i.e. not in the highest tertile) as the thresholds for low grip strength. Analyses were performed using Stata version 14 (Stata Corporation, College Station, Texas, USA). Statistical significance was accepted at $p<0.05$. In a sensitivity analysis, we excluded those who had been diagnosed with diabetes for five years or longer.

Results

Main cohort characteristic by ethnic groups are presented in Table 1. In both men and women diabetes prevalence was highest in south Asians and lowest in whites. Reported physical activity was highest in whites and lowest in south Asians in both sexes. South Asians reported a higher intake of fruit and vegetable per day, a lower intake of oily fish and a lower total energy intake than white and black ethnic groups. Reported alcohol intake was higher in whites than other ethnic groups. South Asian men and women had lower median grip strength, whether expressed in absolute terms or per kg bodyweight, than the other ethnic groups. Figures 1 and 2 show the population distributions for grip strength in the three ethnic groups, showing broadly similar distributions in the black and white European groups for both men and women, but in South Asians, the distribution was shifted left in both men and women by ~5-6 kg in absolute terms and ~0.3-0.5 kg per kg bodyweight, respectively compared with the other ethnic groups. These ethnic differences in grip strength were evident across the full age range within the UK Biobank cohort (see Supplementary Figure S1).

The lower panels of Figure 1 and Figure 2 show the association of hand grip strength Table 2 shows the association between hand-grip strength and diabetes in models adjusted for major confounding variables in men and women, respectively (Model 2). Diabetes prevalence was highest in South Asians and lowest in whites for all levels of grip strength, irrespective of whether grip strength was reported in absolute units or relative to bodyweight ($p < 0.05$ for differences in diabetes prevalence between all ethnic groups). Table 2 shows odds ratio for diabetes per unit change in grip strength. In all ethnicity and sex groups, lower hand-grip strength was associated with higher diabetes risk, after adjustment for age, education, number of years with diabetes and deprivation, whether grip strength was expressed in absolute terms or relative to body weight. Further adjustment for percentage body fat, smoking, dietary intake (fruit and vegetables, alcohol, processed meat, red meat, oily fish), sleep duration and physical activity attenuated these associations somewhat, but they remained statistically significant. The magnitude of association was similar in men and women, but there was a significant ethnicity interaction, with the association between grip strength and diabetes being strongest in white Europeans and somewhat weaker in black and south Asian ethnic groups.

Table 3 shows the attributable risk for diabetes associated with low grip strength (i.e. below the age- and sex-specific population median (Supplementary Table 1)) in each ethnicity and sex group, in analyses adjusted for major confounding variables (Model 2), within the UK Biobank population. The combined effect of high diabetes prevalence and high prevalence of low grip strength in south Asians meant that the attributable risk for diabetes associated with low grip strength was high in both South Asian men and women at 3.9 and 4.2 diabetes cases per 100 individuals, respectively. Attributable risk was also high in black men at 4.3 cases per 100 individuals, but was lower in black women (0.4 cases per 100), and in white men (2.0 cases per 100) and women (0.6 cases per 100). In sensitivity analyses, changing the threshold for low grip strength from the median to the 33rd centile resulted in attributable risk estimates for low grip strength of 2.2 (95%CI: 1.9-2.5), 4.6 (1.9-7.3) and 2.6 (0.9-5.1) diabetes cases per 100 individuals in white European, black and South Asian men, respectively, with corresponding values of 0.8 (0.6-1.0), 1.2 (-0.9-3.2) and 3.3 (1.0-5.5) diabetes cases per 100 individuals in white European, black and South Asian women. Changing the threshold for low grip strength to the 67th centile resulted in attributable risk estimates for low grip strength of 1.8 (1.6-2.0), 4.1 (1.7-6.6) and 3.6 (0.1-7.2) diabetes cases per 100 individuals in white European, black and South Asian men, respectively, and 0.6 (0.4-0.7), 0.1 (-2.0-1.7) and 2.5 (-0.7-5.7) diabetes cases per 100 individuals in white European, black and South Asian women.

To minimise the potential effects of reverse causality confounding the results, a sensitivity analysis was performed excluding all participants with diagnosed diabetes of more than five years duration from the data set. This did not alter any of the overall findings.

Discussion

Lower grip strength was associated with higher prevalence of diabetes, independent of a range of confounding factors including age, adiposity, years with diabetes, physical activity, sedentary behaviour, sleep duration, smoking, alcohol, dietary factors and socio-demographic confounders, across all ethnicities in both men and women. Prevalence of diabetes was ~3-4 fold higher in South Asians and ~2-3 fold higher in black adults compared to white Europeans across all levels of grip strength, but the population distribution for grip strength in south Asians was shifted left by ~5-6 kg in absolute terms and ~0.3-0.5 kg per kg bodyweight, compared to the other ethnic groups. Thus the attributable risk for diabetes associated with low grip strength, at ~4 cases per 100 individuals, was particularly high in South Asian men and women. Attributable risk associated with low grip strength was also high in black men.

Our data revealed a significant interaction with ethnicity in the association between grip strength and diabetes, with the difference in odds for diabetes per unit difference grip strength being higher in white Europeans than the other ethnic groups. However, the higher prevalence of diabetes in south Asians and blacks compared to whites, together with the leftward shift in the population distribution of grip strength in south Asians, resulted in a particularly high attributable risk associated with low grip strength in south Asian adults and black men. In black women the association between grip strength and diabetes was less strong than in other groups, at least when grip strength was expressed in absolute terms, resulting in a lower attributable risk associated with low grip strength, despite a relatively high diabetes prevalence. Identifying and addressing modifiable risk factors in high risk groups is vital in tackling the increasing prevalence of type 2 diabetes. For example, it has been demonstrated that obesity interventions are required at a much lower BMI threshold in black and South Asian populations if they are to be treated at the equivalent risk of diabetes which has translated into ethnicity-specific public health obesity guidance [18]: a BMI of ~22 $kg.m^{-2}$ in south Asians and ~26 $kg.m^{-2}$ in blacks confers equivalent diabetes risk to BMI 30 $kg.m^{-2}$ in whites [3]. However, reducing BMI below 22 $kg.m^{-2}$ in all south Asians is unrealistic. Our results suggest that improving strength, particularly in south Asian adults, and in black men, could potentially provide a complementary strategy in reducing ethnic inequalities in diabetes.

This study was observational and cross-sectional, thus is not possible to conclusively ascertain the direction of the relationship between grip strength and diabetes from the data. However, other data suggest that the potential contribution of reverse causality may be relatively small. Prospective data from other studies have shown that low grip strength is predictive of incident diabetes [6;7], and data from the Health ABC cohort indicated no difference between adults with and without type 2 diabetes in change in grip strength (expressed per kg arm mass) over a 3-year follow-up period [19], suggesting that diabetes itself may not accelerate age-related declines in grip strength. We also adjusted our models for number of years with diabetes, and excluding individuals with longstanding diabetes in a sensitivity analysis did not alter any of our findings. It is unlikely that grip strength, *per se* is causally related to diabetes, but hand-grip strength is highly correlated with leg strength, and provides a valid index of overall limb muscle strength throughout the age range [20]. There is evidence that overall muscle strength could be an important, and potentially causal, risk factor for diabetes. It is important to acknowledge that strength has important genetic component [21], and thus it is important to consider the extent to which it is a modifiable diabetes risk factor. However, intervention studies have shown that muscle strengthening exercise can improve insulin sensitivity and glycaemic control [22;23] and prospective data from over 130,000 men and women indicates that participation in muscle strengthening exercise was associated with reduced risk of incident type 2 diabetes [10;11]. Thus grip strength, which is easy to measure in healthcare and community settings, could potentially be used as a screening tool to identify individuals at increased risk of diabetes due to low overall muscle strength, who may benefit from lifestyle intervention. The major diabetes prevention trials have focused on weight loss and moderate intensity aerobic physical activity [24]. The present results suggest that resistance exercise should be considered as a third important component in future trials. Our data also suggest that south Asian adults and black men should be particularly targeted for interventions to increase strength. This may be particularly important in the context of rapidly increasing rates of diabetes in south Asian populations worldwide [5].

Strengths of this study include its large size which provided sufficient numbers of minority ethnic groups to enable ethnic sub-groups comparisons within the same study. Grip strength was objectively assessed using validated methods, trained staff and standard operating procedures. Direct measurement of body fat enabled robust adjustment for adiposity. Diabetes was ascertained by self-report of a physician diagnosis but this has been shown to agree well with laboratory/clinical diagnosis [25], and in nationally representative US samples, diabetes prevalence determined by self-report only were only slightly lower (less than 1% difference overall) than when based on self-report and laboratory values [26]. Thus, incomplete ascertainment of diabetes cases is likely to be small and unlikely to introduce a systematic error. We did not distinguish between type 1 and type 2 diabetes, but based on UK population data, it is likely that ~90% of cases present would have been type 2 diabetes [27]. If we assume no association between grip strength and type 1 diabetes, this would mean that the association between grip strength and type 2 diabetes is likely to be slightly stronger than the present data indicate; however, this would have no effect on attributable risk estimates (as the slight attenuation of the odds ratio associated with low grip strength, and the slightly higher diabetes prevalence due to inclusion of the type 1 diabetes cases would exactly cancel out). While UK Biobank was not specifically recruited as a nationally-representative sample of the UK population, diabetes prevalence and mean BMI values in the UK Biobank cohort at baseline were comparable to nationally-representative samples across all three ethnic groups [28;29], suggesting that the observations in the present report are potentially broadly generalisable to the UK population. This study was based in the UK. While associations between strength and odds of diabetes are likely to be similar for an ethnic group irrespective of location, attributable risk estimates depend on the prevalence of diabetes and population distribution of strength which may differ between the UK and other countries.

In conclusion, this study demonstrated independent associations between muscular strength and diabetes risk in white European, south Asian and black adults living in the UK. Low strength was associated with a disproportionately large number of diabetes cases in the south Asian adults and black men in the UK Biobank population, making a clear case for future randomised controlled trials of interventions to improve strength in these populations.

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This research has been conducted using the UK Biobank resource. UK Biobank was established by the Wellcome Trust medical charity, Medical Research Council, Department of Health, Scottish Government and the Northwest Regional Development Agency. It has also had funding from the Welsh Assembly Government and the British Heart Foundation. UEN was funded by the Niger Delta Development Commission, Nigeria. The research was designed, conducted, analysed, and interpreted by the authors entirely independently of the funding sources.

Conflicts of Interest

The authors have no relevant conflicts of interest.

Author contributions

UEN and CACM contributed to the conception and design of the study, performed the statistical analyses, interpreted the data, reviewed the manuscript and approved the final version to be published. DFM contributed to the conception and design of the study, advised on all statistical aspects, interpreted the data, reviewed the manuscript and approved the final version to be published. NS contributed to the conception and design of the study, interpreted the data, reviewed the manuscript and approved the final version to be published. JPP obtained the data, contributed to the conception and design of the study, interpreted the data, reviewed the manuscript and approved the final version to be published. JMRG contributed to the conception and design of the study, advised on data analysis, interpreted the data, drafted the manuscript and approved the final version to be published.

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Table 1. Descriptive characteristics of study population by sex and ethnicity

	Men			Women		
	White	Black	South Asian	White	Black	South Asian
N	184009	3085	4457	224521	4181	4083
Age (y)	57 (50; 63)	50 (45; 57)	52 (45; 59)	57 (50; 63)	50 (45; 57)	52 (46; 59)
BMI ($kg.m^{-2}$)	27.2 (24.9; 29.9)	27.9 (25.5; 30.6)	26.5 (24.3; 29.0)	26.0 (23.4; 29.5)	29.5 (26.0; 33.5)	26.5 (23.9; 29.8)
Weight (kg)	84.4 (76.4; 93.7)	84.2 (76.3; 93.9)	77.0 (69.6; 85.3)	68.9 (61.6; 78.3)	68.9 (68.3; 88.8)	65.2 (58.1; 73.7)
Body fat (%)	25.1 (21.3; 28.8)	25.5 (21.7; 28.9)	25.9 (22.6; 29.2)	36.6 (31.8; 41.2)	40.3 (35.4; 44.2)	37.8 (33.7; 42.0)
Fat-free mass (kg)	63.4 (58.7; 68.7)	63.1 (58.2; 68.9)	57.2 (52.7; 62.1)	44.0 (41.2; 47.3)	46.7 (43.3; 50.7)	40.5 (37.9; 43.8)
Hand grip strength (kg)	40.0 (34.0; 46.0)	40.5 (34.0; 47.5)	34.0 (28.0; 40.0)	23.5 (20.0; 28.0)	25.0 (20.5; 30.0)	19.0 (15.0; 23.5)
Hand grip strength (kg/kg)	0.47 (0.40; 0.54)	0.48 (0.39; 0.56)	0.44 (0.36; 0.52)	0.34 (0.27; 0.41)	0.32 (0.25; 0.39)	0.29 (0.23; 0.37)
Physical activity ($MET.h.week^{-1}$)	27.3 (10.8; 59.1)	22.0 (7.5; 51.3)	18.6 (6.6; 43.6)	23.5 (8.8; 50.4)	20.3 (7.33; 44.2)	16.5 (5.8; 40.0)
Diabetes, n (%)	9,936 (5.4)	362 (11.8)	764 (17.4)	6,739 (3.0)	392 (9.4)	518 (12.8)
Total energy intake (KJ/day)	2237 (1874; 2648)	1989 (1480; 2594)	1961 (1529; 2470)	1917 (1613; 2257)	1845 (1414; 2364)	1709 (1346; 2160)
Fruit & vegetable (g/day)	267 (187; 377)	270 (160; 427)	323 (213; 487)	323 (240; 433)	347 (213; 487)	373 (243; 533)
Oily fish (portion/week)	1.0 (0.5; 1.0)	1.0 (0.5; 3.0)	0.5 (0.5; 1.0)	1.0 (0.5; 1.0)	1.0 (0.5; 3.0)	0.5 (0; 1.0)
Red meat (portion/week)	1.5 (1.5; 2.5)	2.0 (1.5; 4.0)	1.0 (0.5; 2.0)	1.5 (1.5; 2.0)	1.5 (1.0; 2.5)	1.0 (0; 1.5)
Processed meat (portion/week)	2 (1; 3)	2 (1; 3)	1 (1; 2)	2 (1; 2)	1 (1; 2)	1 (0; 2)
Alcohol (g/day)	16 (0; 34)	0 (0; 15)	0 (0; 12)	6 (0; 19)	0 (0; 5)	0 (0; 1)
Sleep duration (h/day)	7 (7; 8)	7 (6; 7)	7 (6; 8)	7 (7; 8)	7 (6; 8)	7 (6; 8)
Smoking, n (%)						

Never	92,249 (50.3)	1,852 (60.5)	2,933 (66.6)	133,045 (59.5)	3,235 (77.9)	3,693 (90.8)
Past-smoking	68,744 (37.5)	691 (22.6)	804 (18.3)	71,046 (31.8)	551 (13.3)	232 (5.7)
Current smoking	22,435 (12.2)	519 (17.0)	667 (15.2)	19,707 (8.8)	369 (8.9)	141 (3.5)
Deprivation, n (%)						
1 (least)	39,168 (21.3)	93 (3.0)	389 (8.7)	46,966 (20.9)	124 (3.0)	417 (10.2)
2	38,114 (20.7)	140 (4.6)	436 (9.8)	46,755 (20.9)	194 (4.6)	408 (10.0)
3	37,305 (20.3)	240 (7.8)	624 (14.0)	46,779 (20.9)	366 (8.8)	643 (15.8)
4	35,761 (19.5)	642 (20.9)	1,260 (28.3)	44,777 (20.0)	874 (20.9)	1,232 (30.2)
5 (most)	33,428 (18.2)	1,955 (63.7)	1,741 (39.1)	38,986 (17.4)	2,619 (62.7)	1,377 (33.8)

Values are median (interquartile ranges); BMI - body mass index

Table 2. Association between grip strength and risk of diabetes in White, Black and South Asian men and women

	Men				Women			
	White	Black	South Asian	$P_{grip*eth}$	White	Black	South Asian	$P_{grip*eth}$
Absolute handgrip strength [per 5 kg increase]								
Model 1	0.84 (0.83-0.85)	0.86 (0.80- 0.92)	0.90 (0.85-0.94)	0.005	0.84 (0.82-0.86)	0.93 (0.86-1.01)	0.90 (0.83-0.98)	0.040
Model 2	0.85 (0.84-0.86)	0.86 (0.80-0.93)	0.89 (0.85-0.94)	<0.0001	0.88 (0.86-0.90)	0.95 (0.87-1.03)	0.93 (0.85-1.01)	<0.0001
Absolute handgrip strength [per SD increase]								
Model 1	0.76 (0.74-0.77)	0.80 (0.72-0.89)	0.84 (0.77-0.92)	0.012	0.79 (0.77-0.81)	0.91 (0.82-1.00)	0.85 (0.77-0.94)	0.031
Model 2	0.76 (0.75-0.78)	0.81 (0.72-0.91)	0.83 (0.75-0.91)	<0.0001	0.84 (0.82-0.87)	0.94 (0.84-1.04)	0.87 (0.78-0.97)	<0.0001
Relative handgrip strength [per 0.05 kg/kg increase]								
Model 1	0.74 (0.73-0.75)	0.84 (0.80-0.88)	0.87 (0.84-0.90)	<0.0001	0.72 (0.71-0.72)	0.84 (0.79-0.88)	0.84 (0.79-0.88)	<0.0001
Model 2	0.85 (0.84-0.86)	0.88 (0.83-0.93)	0.92 (0.88-0.96)	0.062	0.87 (0.86-0.89)	0.93 (0.86-0.99)	0.91 (0.86-0.97)	0.003
Relative handgrip strength [per SD increase]								
Model 1	0.50 (0.49-0.52)	0.67 (0.60-0.75)	0.73 (0.67-0.79)	<0.0001	0.50 (0.48-0.51)	0.69 (0.61-0.77)	0.70 (0.63-0.77)	<0.0001
Model 2	0.69 (0.67-0.71)	0.74 (0.65-0.85)	0.82 (0.74-0.91)	0.062	0.75 (0.73-0.78)	0.85 (0.74-0.99)	0.82 (0.73-0.93)	0.003

Values are odds ratios (with 95% confidence intervals) for the association of a unit change in grip strength, expressed either in kg or in kg per kg bodyweight, in each sex and ethnicity group. P values refer to the grip strength x ethnicity interaction. Statistical models are as follow:

Model 1: Adjusted for age, education, number of years with diabetes, and socioeconomic status

Model 2: Model 1, plus adjustment for percentage body fat, smoking, dietary intake (fruit and vegetables, alcohol, processed meat, red meat, oily fish), sleep duration and physical activity

Table 3. Diabetes prevalence and attributable risk for diabetes of low grip strength in white, black and south Asian men and women

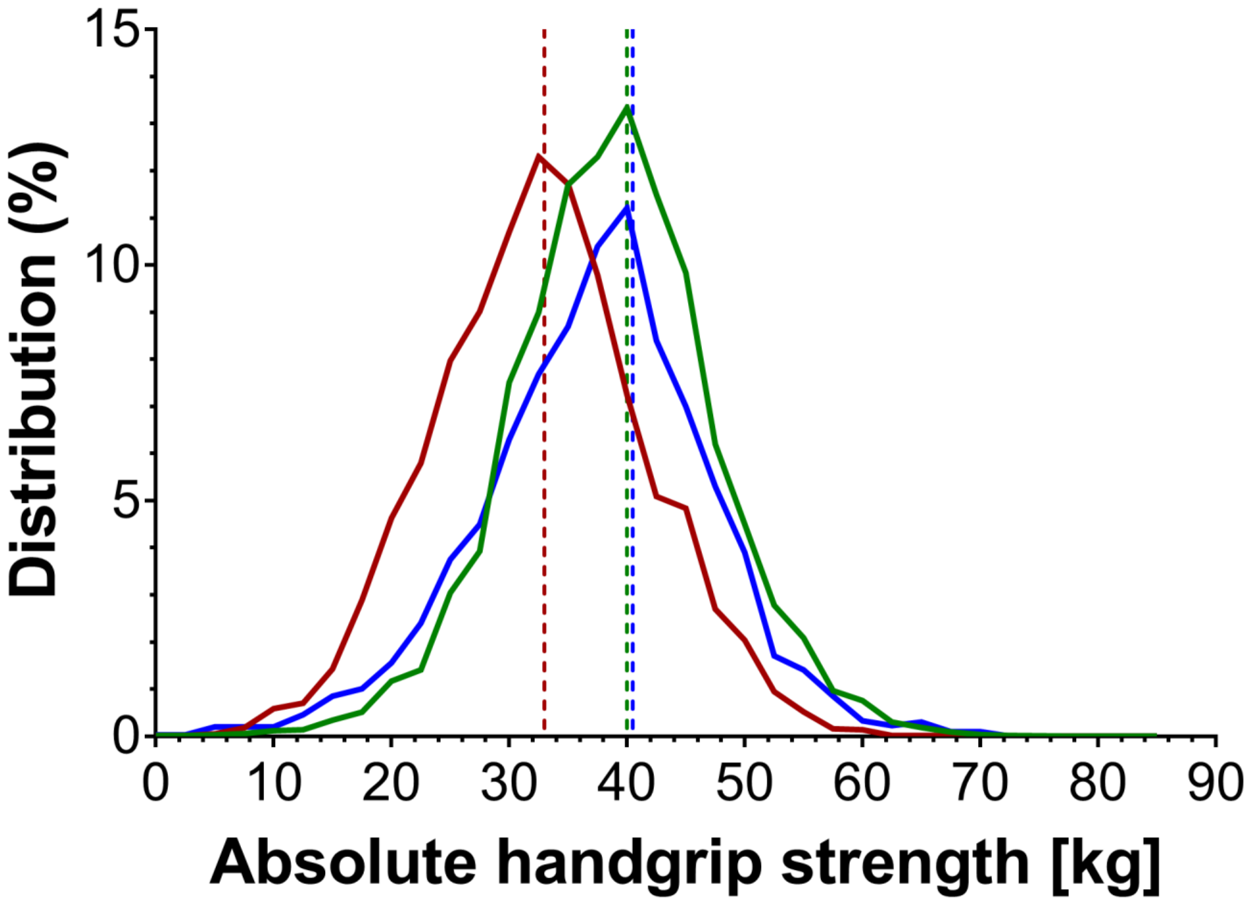
	White	Black	South Asian
Men			
Prevalence of diabetes (%)	6.5 (6.3-6.6)	14.6 (12.9-16.4)	18.6 (17.2-19.9)
Prevalence of low grip strength (%)	49.4	52.1	79.1
Odds ratio for diabetes associated with low grip strength	1.5 (1.4-1.6)	1.6 (1.2-2.0)	1.4 (1.1-1.7)
Expected prevalence of diabetes if individuals with low grip strength increased grip strength above the population median (%)	4.4 (4.3-4.6)	10.2 (8.6-12.1)	14.6 (12.3-17.3)
Attributable risk associated with low grip strength (diabetes cases per 100 individuals)	2.0 (1.7-2.2)	4.3 (1.9-6.8)	3.9 (1.1-6.7)
Women			
Prevalence of diabetes (%)	3.4 (3.2-3.5)	10.0 (8.8-11.3)	13.6 (12.4-14.7)
Prevalence of low grip strength (%)	51.5	49.2	81.1
Odds ratio for diabetes associated with low grip strength	1.2 (1.1-1.3)	1.1 (0.8-1.3)	1.6 (1.1-2.0)
Expected prevalence of diabetes if individuals with low grip strength increased grip strength above the population median (%)	2.8 (2.7-2.9)	9.6 (8.3-10.9)	9.4 (7.4-11.8)
Attributable risk associated with low grip strength (diabetes cases per 100 individuals)	0.6 (0.4-0.7)	0.4 (-1.4-2.3)	4.2 (1.6-6.6)

Low grip strength defined as grip strength below the age- and sex-specific overall UK Biobank population median. All values adjusted for age, education, number of years with diabetes, socioeconomic status, percentage body fat, smoking, dietary intake (fruit and vegetables, alcohol, processed meat, red meat, oily fish), sleep duration and physical activity. Values in brackets are 95% CI.

Figure Legends

Figure 1. Distribution of grip strength expressed in absolute terms (panel a) and relative to bodyweight (panel b), and prevalence of diabetes according to absolute (panel c) and relative (panel d) grip strength in white (green), black (blue) and south Asian (red) men in the UK Biobank population. Diabetes prevalence values adjusted for age, education, number of years with diabetes, socioeconomic status, percentage body fat, smoking, dietary intake (fruit and vegetables, alcohol, processed meat, red meat, oily fish), sleep duration and physical activity. Dotted vertical lines on top panels represent median grip strength values for each ethnic group.

Figure 2. Distribution of grip strength expressed in absolute terms (panel a) and relative to bodyweight (panel b), and prevalence of diabetes according to absolute (panel c) and relative (panel d) grip strength in white (green), black (blue) and south Asian (red) women in the UK Biobank population. Diabetes prevalence values adjusted for age, education, number of years with diabetes, socioeconomic status, percentage body fat, smoking, dietary intake (fruit and vegetables, alcohol, processed meat, red meat, oily fish), sleep duration and physical activity. Dotted vertical lines on top panels represent median grip strength values for each ethnic group.



15
10
5
0
Distribution (%)
0
10
20
30
40
50
60
70
80
90
Absolute handgrip strength [kg]

Figure 1a

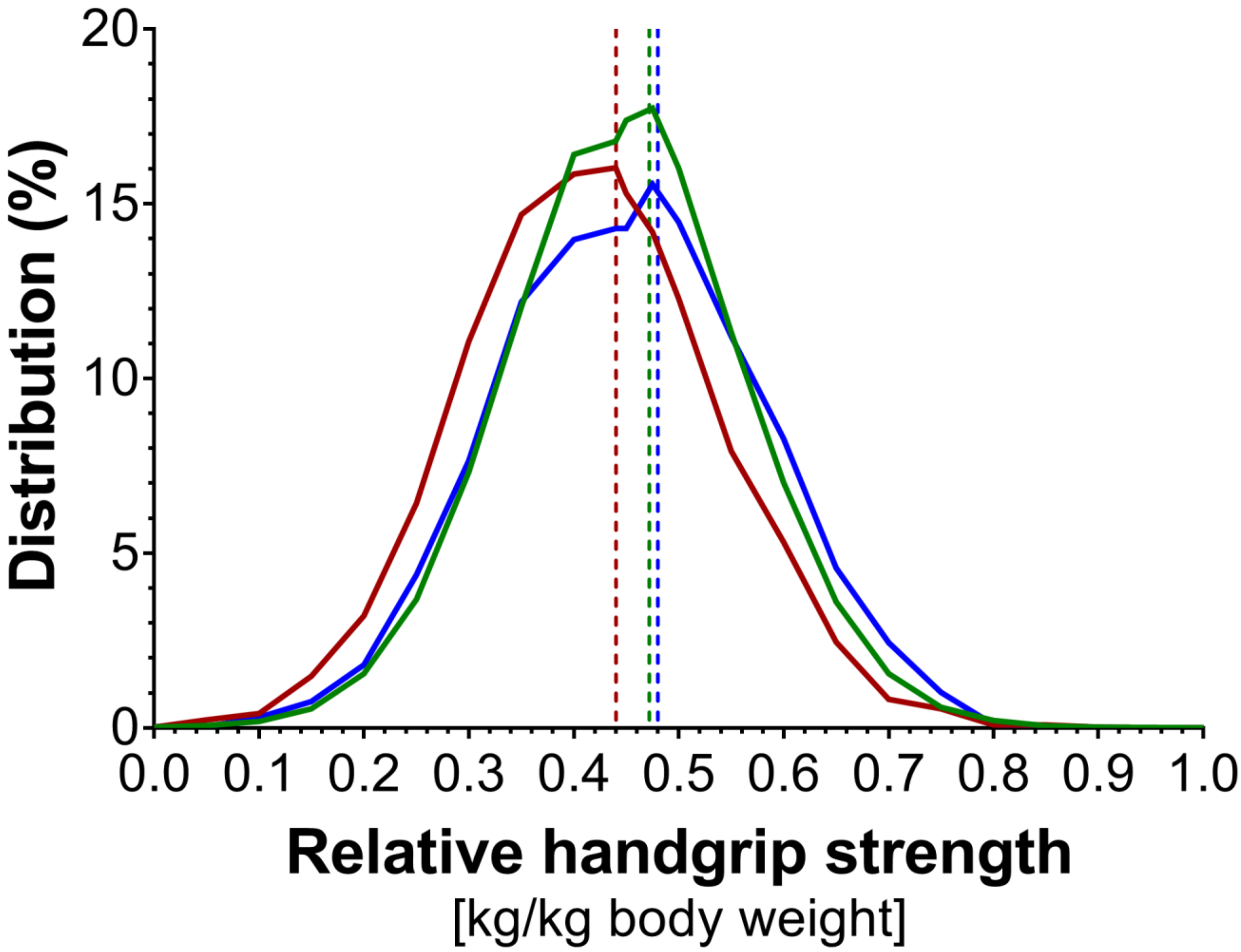

Distribution (%)
20
15
10
5
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Relative handgrip strength
[kg/kg body weight]

Figure 1b

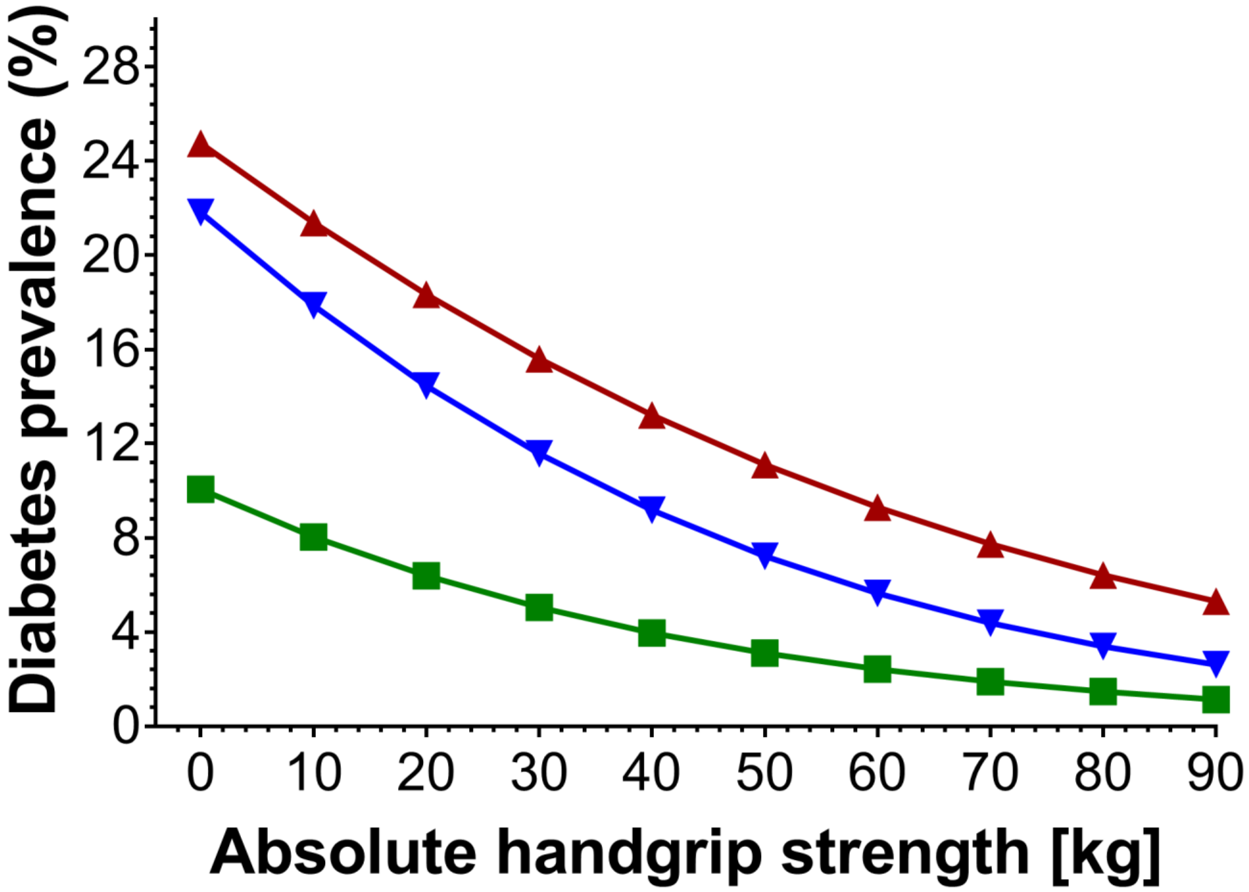

Diabetes prevalence (%)
28
24
20
16
12
8
4
0
0
10
20
30
40
50
60
70
80
90
Absolute handgrip strength [kg]

Figure 1c

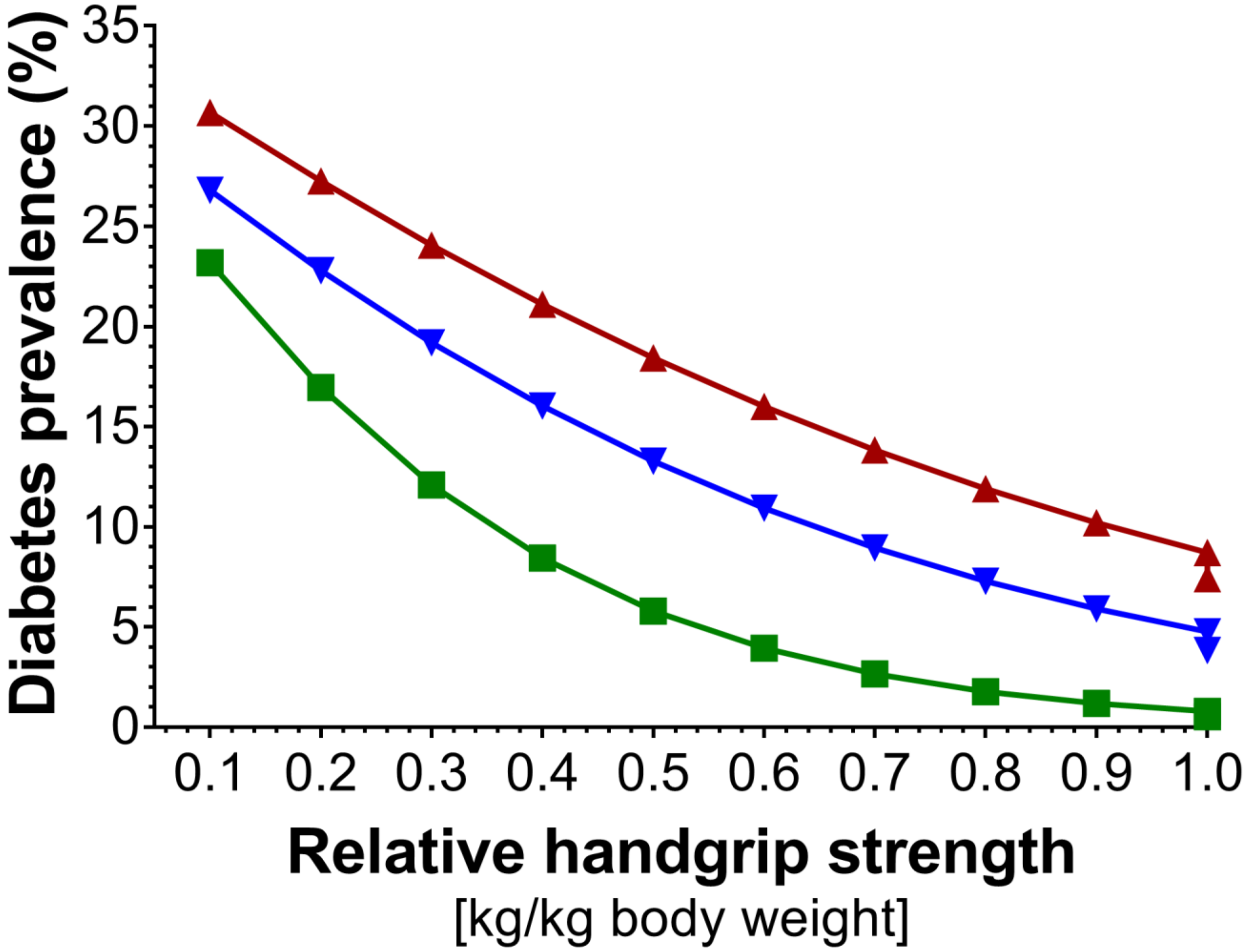

Diabetes prevalence (%)
35
30
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Relative handgrip strength
[kg/kg body weight]

Figure 1d

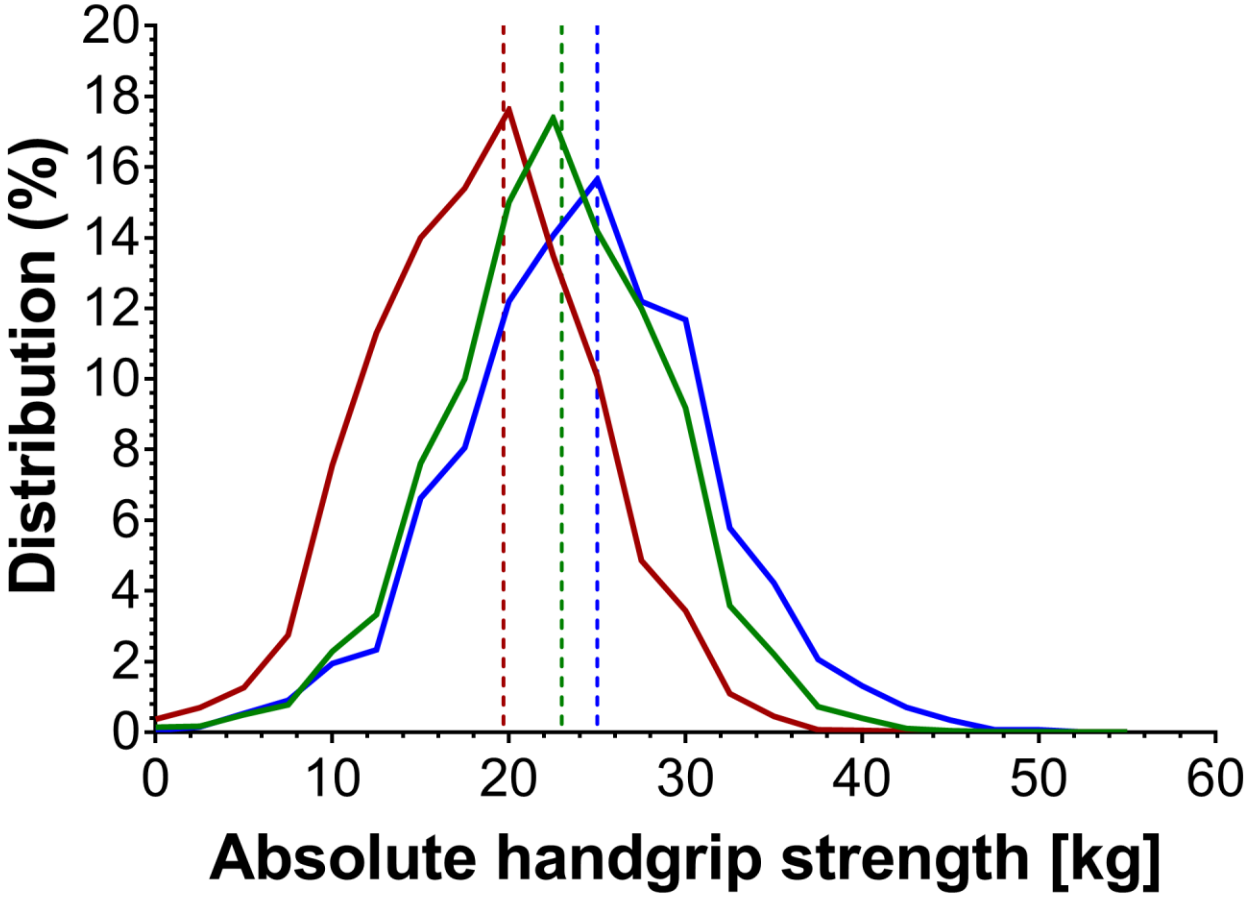

Distribution (%)
Absolute handgrip strength [kg]
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60

Figure 2a

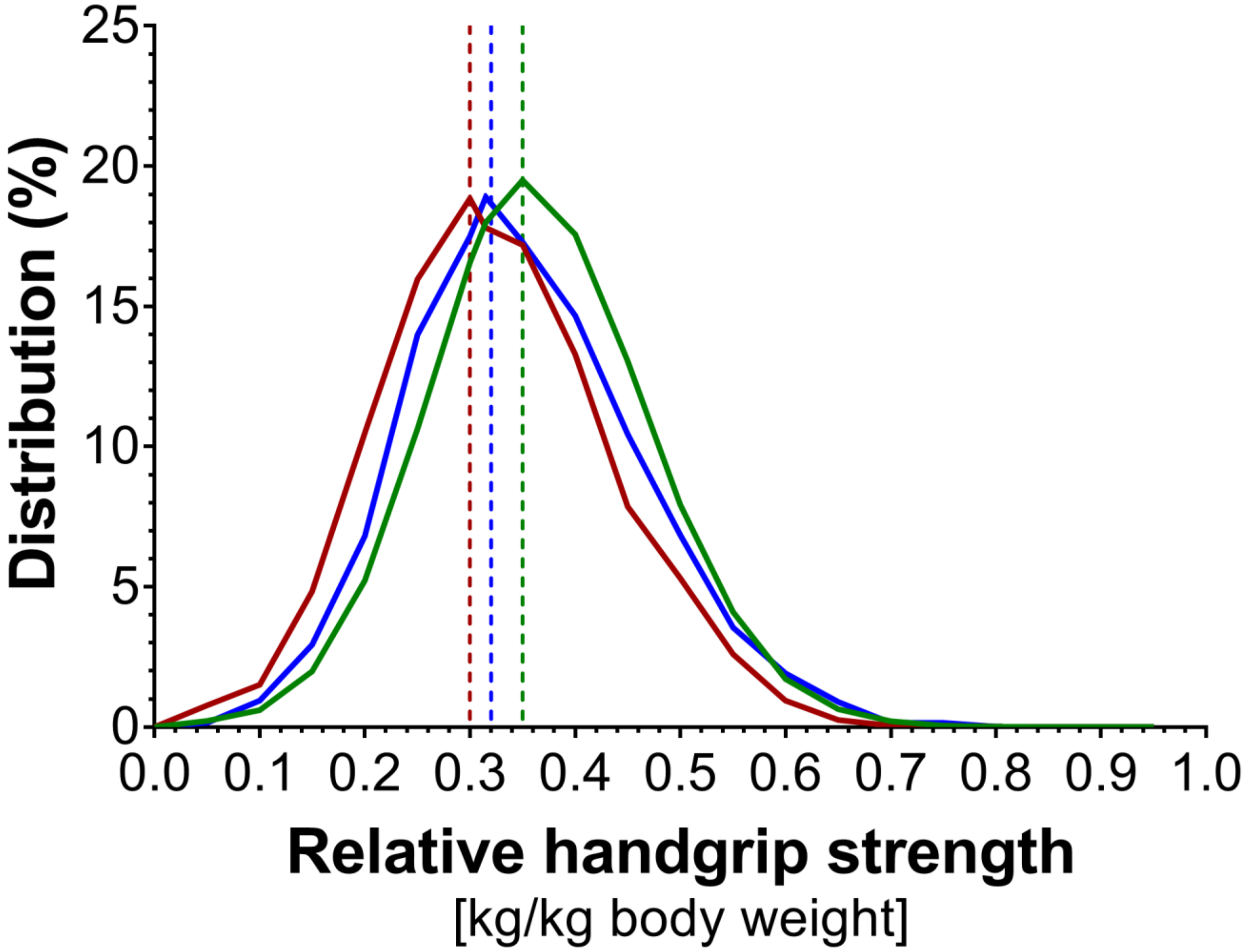
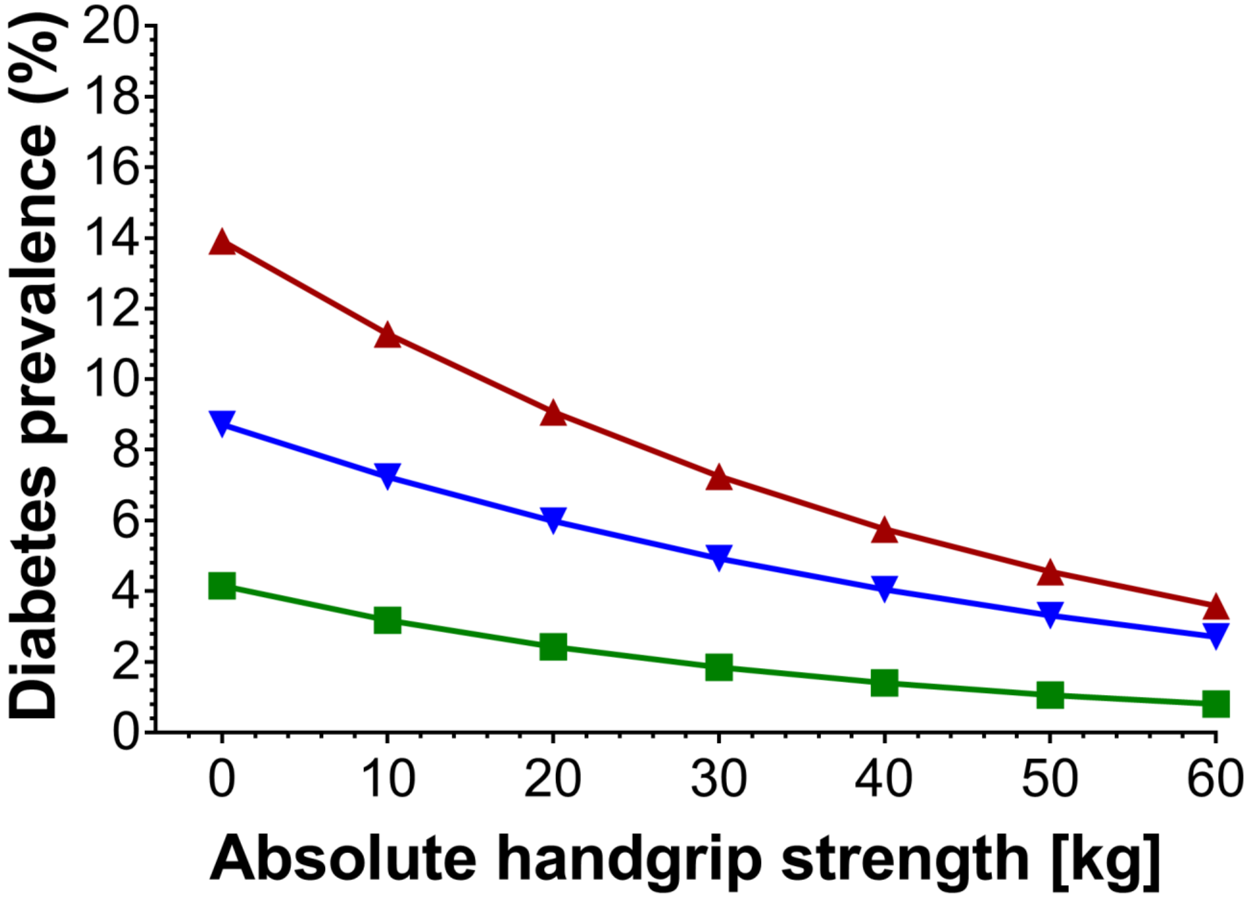
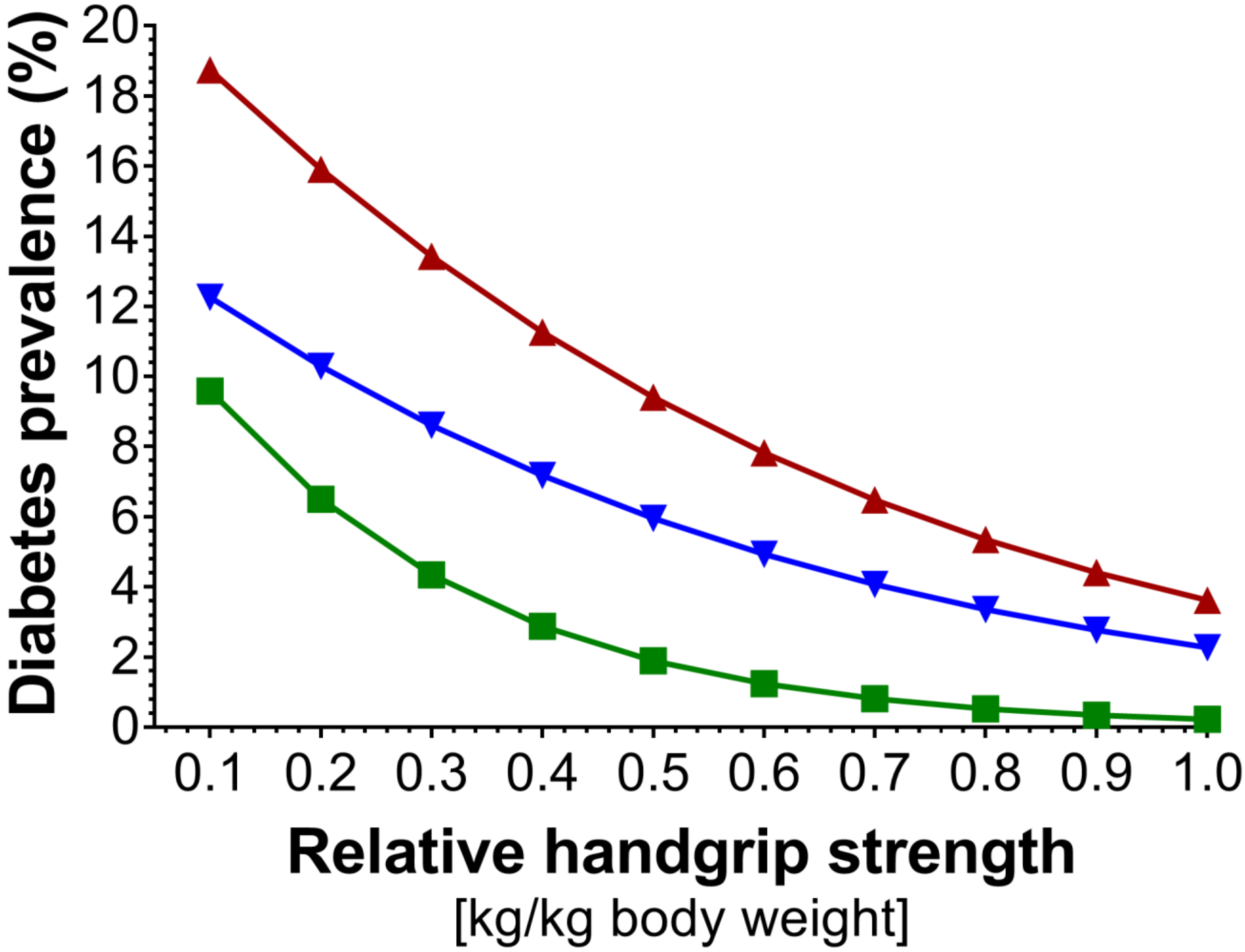

25
20
15
10
5
0
Distribution (%)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Relative handgrip strength
[kg/kg body weight]

Figure 2b



Diabetes prevalence (%)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
Absolute handgrip strength [kg]

Figure 2c

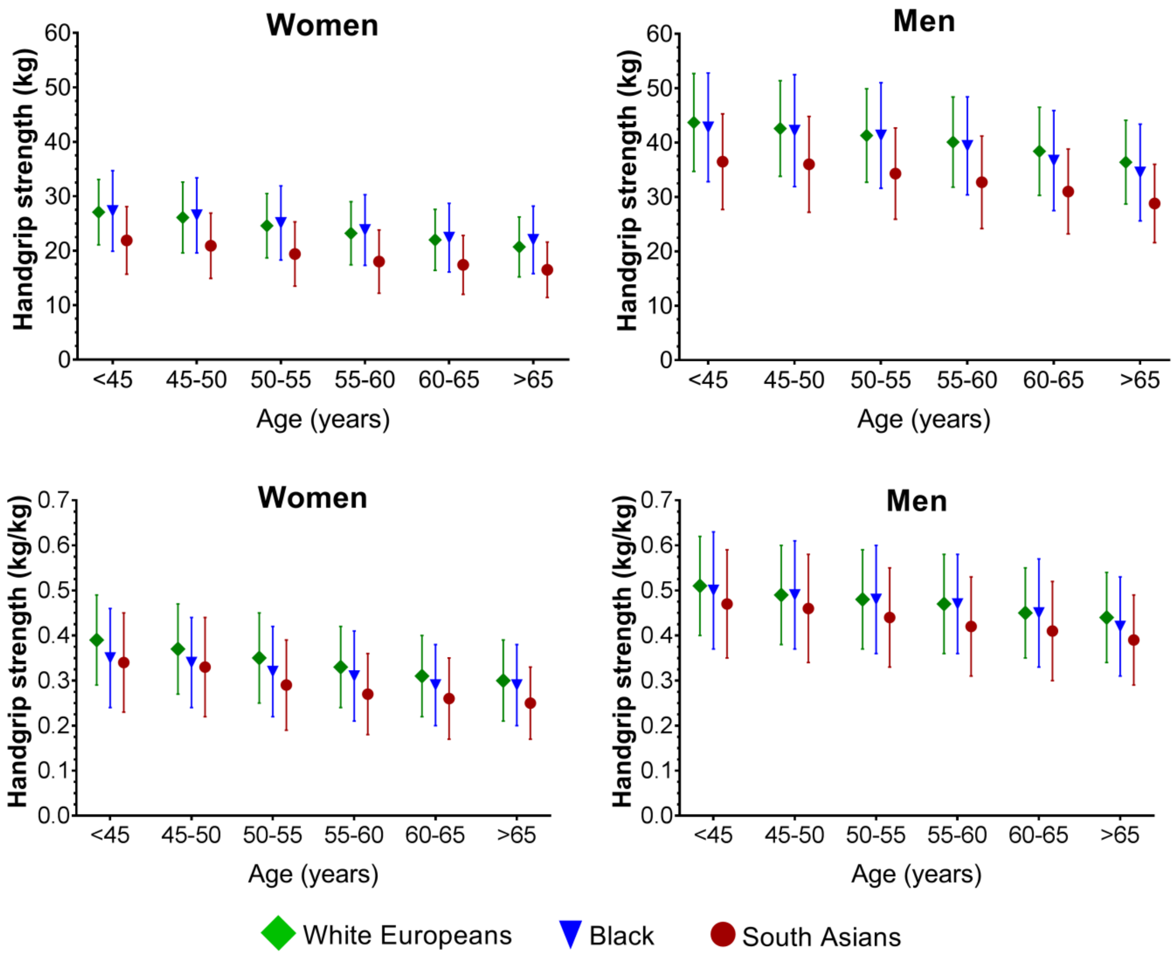


Diabetes prevalence (%)
20
18
16
14
12
10
8
6
4
2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Relative handgrip strength
[kg/kg body weight]

Figure 2d

Supplementary Table 1. Age- and sex-specific values for median grip strength in men and women in the UK Biobank population.

	Median grip strength (kg)	
Age range	**Women**	**Men**
40-44 years	27.0	43.0
45-49 years	26.0	42.0
50-54 years	25.0	41.0
55-59 years	23.0	40.0
60-64 years	22.0	38.5
65+ years	21.0	36.0



Supplementary Figure S1. Handgrip strength by age-group in women (left panels) and men (right panels), expressed in absolute terms (top panels) and per kg bodyweight (bottom panels), in white European, south Asian and black ethnic groups. Data are presented as mean ± SD values.