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Muscle strength in youth and cardiovascular risk in young adulthood (the European Youth Heart Study)

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ABSTRACT

Background Whether muscle strength in youth is related to cardiovascular risk later in life independent of cardiorespiratory fitness is unclear.

Methods We examined the independent association of isometric muscle strength in youth with cardiovascular risk factors in young adulthood using data from the Danish European Youth Heart Study; a population-based prospective cohort study among boys and girls (n=332) followed for up to 12 years. In youth maximal voluntary contractions during isometric back extension and abdominal flexion were determined using a strain-gauge dynamometer and cardiorespiratory fitness was obtained from a maximal cycle ergometer test. Cardiovascular risk factors were obtained in youth and in young adulthood. Associations were examined using multivariable-adjusted regression models including major confounding factors.

Results Each 1 SD difference in isometric muscle strength in youth (0.17 N/kg) was inversely associated with body mass index (BMI; −0.60 kg/m^2, 95% CI −0.97 to −0.22), triglyceride (−0.09 mmol/l, 95% CI −0.16 to −0.02), diastolic blood pressure (BP) (−1.22 mm Hg, 95% CI −2.15 to −0.29) and a composite cardiovascular risk factor score (−0.61 SD, 95% CI −1.03 to −0.20) in young adulthood in multivariable-adjusted analyses including fitness. Associations to triglyceride, diastolic BP and the cardiovascular risk factor score remained with additional adjustment for waist circumference or BMI. Each 1 SD difference in isometric muscle strength in youth was significantly associated with 0.59 (95% CI 0.40 to 0.87) lower odds of general overweight/obesity in young adulthood (p=0.007) and was marginally associated with incident raised BP, raised triglyceride and low high-density lipoprotein cholesterol.

Conclusions This study suggests that greater isometric muscle strength in youth is associated with lower levels of cardiovascular risk factors in young adulthood independent of fitness, adiposity and other confounding factors.

INTRODUCTION

In children and youth low cardiorespiratory fitness is a well-established risk factor for developing cardiovascular disease (CVD) risk factors such as obesity, metabolic syndrome and raised blood pressure (BP).[1 2] While prospective studies have established this in detail;[3] the importance of muscle strength remains less clear. Among adult men, some evidence suggests that low muscle strength is associated with premature mortality independent of cardiorespiratory fitness[4] and engagement in weight training protects against coronary heart disease (CHD)[5] and type 2 diabetes[6] independent of aerobic activity. These epidemiological studies provide support to promote muscle-strengthening activities in addition to aerobic physical activity (PA) for primary prevention in adults. In the current guidelines for PA for children and youth it is recommended that muscle-strengthening activities should be included as part of the 60 min/day of moderate-to-vigorous PA that are endorsed to be largely aerobic.[7 8] Children and adolescents engaging in muscle-strengthening activities can increase their muscular strength,[9] indicating that muscle strength is a marker of participation in muscle-strengthening activities. A recent prospective study based on Swedish male adolescents reported that low muscle strength was inversely associated with premature mortality, although this analysis was not adjusted for cardiorespiratory fitness.[10] We are not aware of prospective studies examining the influence of muscle strength in childhood or youth on CVD risk factors in adulthood independent of cardiorespiratory fitness and other important determinant of CVD risk.

In this study we examined the association of isometric muscle strength in youth with cardiovascular risk factors in young adulthood independent of cardiorespiratory fitness among Danish boys and girls followed up to 12 years in the European Youth Heart Study (EYHS).

METHODS

Design

The current study is based on the Danish cohorts of the EYHS, an ongoing international population-based multicentre study that addresses CVD risk factors in children and adolescents. A detailed description of the sampling procedure of the EYHS is provided elsewhere.[11] In this study, a random sample of 658 15-year-old adolescents were invited to participate in 1997–1998, of whom 429 (65%) agreed to take part in the study. In 2003–2004, another random sample of 771 15-year-old adolescents was invited of whom 444 (58%) agreed to take part. In 2009–2010, a 6-year or 12-year follow-up was conducted where all originally invited participants from 1997–1998 to 2003–2004 were invited again, 281 (43%) and 369 (48%) from the 1997–1998 to 2003–2004 originally invited participated, respectively. Isometric muscle strength was assessed in a subgroup of 243 participants in 1997–1998 (57%) and in 441 (99%) in 2003–2004. The eligible cohort for the current analyses was n=332 individuals who had complete data on all exposure and outcome variables (229 individuals with 6-year follow-up and 103 individuals with 12-year follow-up). Ninety-four per cent of the population at baseline was postpubertal based

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on Tanner's stage evaluation performed by trained researchers (pubic hair stages for boys and Tanner's breast development stages for girls) and 93% were white (Caucasian). The local scientific ethics committee approved the study and all participants gave informed consent to participate.

Isometric muscle strength

Isometric muscle strength was obtained during maximal voluntary contraction (MVC) of abdominal and back muscles. The participants were standing upright and positioned with a strap around the shoulders connected to a strain-gauge dynamometer.[12] Assessment of abdominal strength was performed with the back against the dynamometer performing maximal forward flexion. For MVC of the low back muscles, the participants were positioned with the front against the dynamometer performing maximal backward extension. Isometric muscle strength was calculated as the mean of abdominal and back strength (Newton (N)) divided by body weight (N/kg). A previous study among adults have reported high reliability of these particular isometric strength measures (intraclass correlation coefficient >0.9).[13]

Cardiorespiratory fitness

Cardiorespiratory fitness was assessed during a progressive maximal ergometer bicycle test (Ergomedic 839; Monark, Varberg, Sweden) as previously described.[11] Heart rate (HR) was recorded every 5 s throughout the test using a HR monitor (Polar Vantage, Finland). Criteria for a maximal effort were HR of 185 bpm or greater, and a subjective judgement by the observer that the participant could no longer continue, even after encouragement. Maximal power output (wattmax) from the test was used to estimate maximal oxygen uptake using the following equation VO_2-max (ml/min)=0.465+(0.0112×wattmax) +(0.172×sex), where sex is boys=1 and girls=0.[14] VO_2-max was subsequently divided by body weight. The fitness test is highly reproducible (coefficient of variation 2.5–4.8%) and a previous validation study in 15-year-olds have shown that this measure is highly correlated with VO_2-max assessed directly ($r > 0.90$, $p < 0.001$).[15]

Other covariates

Information on watching television (TV) at baseline was obtained using a computer-based questionnaire as described previously.[11] Two questions about the amount of time watching TV (before and after school) were combined to create a summary variable of daily TV watching time (hours/day).[16] Smoking status, monthly frequency soft drinks, fruit and vegetable intake were obtained by self-report in adolescence using the same questionnaire. Family history of CVD (paternal or maternal, yes/no) and parental educational level were obtained by parental self-report. Parental educational status was defined according to the International Standard Classification of Education (ISCED, 1997). However, as the details obtained from the description of education was insufficient, the ISCED seven-point scale was changed to three new groups (1 = basic education; 2 = secondary or postsecondary education and 3 = tertiary education).

Cardiovascular risk factors

Body height, body weight, and waist circumference (WC) were measured using standard anthropometric procedures.[11] Fasting blood samples (overnight) were taken in the morning from the antecubital vein. Samples were aliquoted and separated within 30 min, and then stored at −80°C until they were transported to WHO-certified laboratory in Bristol and Cambridge (UK), for analysis at baseline and in Cambridge (UK) at follow-up. Samples were analysed for serum glucose, high-density lipoprotein cholesterol (HDL-C) and triglyceride. Triglyceride was analysed using the lipase/glycerol kinase/glycerol phosphate oxidase enzymatic method. HDL was analysed using the homogeneous polyanion/cholesterol esterase/oxidase enzymatic method. Glucose was analysed using the hexokinase method. Blood lipids and glucose were measured on an Olympus AU600 autoanalyzer (Olympus Diagnostica, Hamburg, Germany) at baseline and on a Dade Behring Dimension RxL autonalyzer (Siemens Healthcare, Camberley, UK) at follow-up. Between-laboratory correlations in lipids, and glucose for 30 randomly selected samples analysed at both laboratories were 0.94–0.98 at baseline.[17]

Resting BP was measured with a Dinamap paediatric and adult neonatal vital signs monitor (model XL, Critikron, Inc, Tampa, Florida, USA) using an appropriate cuff size (evaluated via arm circumference). After 5 min of seated rest, five measurements were taken at 2 min intervals with the mean of the final three measurements used in all analyses.

We calculated a continuous composite CVD risk z-score using components of the metabolic syndrome suggested by the American Heart Association (AHA) and the National Heart, Lung and Blood Institute (NHLBI).[18] Thus, WC, the mean of diastolic and systolic BP, triglycerides, HDL (inverted) and fasting glucose were standardised and subsequently summed to create a continuous z-score.[19] Standardisation in young adulthood (follow-up) was carried out according to the baseline distribution (mean and SD) of each risk factor.

Abdominal obesity, raised BP, raised triglycerides, low HDL and raised fasting plasma glucose were defined according to Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III).[20]

Statistics

We examined the associations of isometric muscle strength in adolescence with cardiovascular risk factors in young adulthood using multiple linear regression with baseline levels of respective risk factors included as a covariate. First, we adjusted models for age at baseline, follow-up time, sex and recruitment period. We then ran multivariable analyses adjusting for baseline information on TV watching, parental educational level, smoking, family history of CVD, frequency of intake of soft drinks and intake of fruit and vegetables. Furthermore, we additionally adjusted for cardiorespiratory fitness and body mass index (BMI) or WC. Standard linear regression diagnostics, including examining linearity and normality of residuals, revealed no indication of violation of assumptions.

We also analysed the association of isometric muscle strength with the odds of incident general overweight or obesity, abdominal obesity, raised BP, raised triglyceride and low HDL using multiple logistic regression adjusting for the same covariates as in the linear models. In these analyses we excluded prevalent cases of each respective risk factor at baseline. As the number of incident cases for some of the outcomes was low (eg, n=24 for raised BP) we performed a sensitivity analysis using propensity score matching[21] to comply with '≥10 outcome events per covariate' assumption including the same confounders as in the multivariable adjusted models. We did not proceed with analysing the risk of incident metabolic syndrome (according to AHA and NHLBI) and impaired fasting glucose in young adulthood, as the numbers of cases for these outcomes were <20.

Finally, we examined the association of isometric muscle strength in adolescence with cardiovascular risk in young

Table 1 Sex-adjusted baseline characteristics by tertiles of maximal voluntary isometric muscle strength in adolescence

	Isometric muscle strength in adolescence (tertiles)			
	0.71 (0.08) N/kg (n=110)	0.86 (0.08) N/kg (n=111)	1.04 (0.08) N/kg (n=111)	p Value
Age (years)	15.6 (0.4)	15.6 (0.4)	15.6 (0.4)	0.43
BMI (kg/m^2)	21.8 (2.6)	20.7 (2.5)	20.4 (2.6)	<0.001
Waist circumference (cm)	75.0 (6.4)	72.2 (6.2)	70.4 (6.6)	<0.001
Systolic BP (mm Hg)	109.7 (9.7)	110.0 (9.5)	108.4 (9.9)	0.44
Diastolic BP (mm Hg)	61.0 (6.6)	61.5 (6.4)	60.6 (6.7)	0.34
Triglyceride (mmol/l)	0.97 (0.47)	0.88 (0.46)	0.78 (0.48)	0.01
HDL-C (mmol/l)	1.40 (0.31)	1.42 (0.30)	1.41 (0.32)	0.86
Glucose (mmol/l)	5.16 (0.39)	5.10 (0.38)	4.97 (0.39)	0.002
Composite CVD risk z-score (SD)	0.89 (2.48)	0.01 (2.41)	−0.90 (2.53)	<0.001
Cardiorespiratory fitness (ml O_2/min/kg)	43.6 (5.5)	46.9 (5.4)	48.7 (5.6)	<0.001
Television watching (hours/day)	1.8 (1.1)	1.5 (1.1)	1.3 (1.1)	0.02
Soft drinks (servings/month)	7.9 (8.6)	9.2 (8.6)	10.4 (8.6)	0.10
Fruits and vegetables (servings/month)	34.1 (17.3)	37.7 (16.9)	43.9 (17.7)	<0.001
Parental education level (% 1/2/3)*	9.6/36.2/54.2	10.1/22.0/67.8	7.5/21.7/70.8	0.10
Family history of CVD (%)	34.1	35.3	24.7	0.22
Smoking (%)	13.1	14.8	16.7	0.79

Data are means (SD) or numbers (%) and are standardised according to the sex distribution of the study population.
*Based on educational level (International Standard Classification of Education (ISCED) (UNESCO 1997). The ISCED levels 1 and 2 were grouped, 3 and 4 were grouped and 5, 6 and 7 were grouped.
BP, blood pressure; BMI, body mass index; CVD, cardiovascular disease; HDL-C, high-density lipoprotein cholesterol; N, Newton.

adulthood stratified by sex, follow-up time (6 or 12 years) and cardiorespiratory fitness level (sex-specific below or above the median of cardiorespiratory fitness).

We also performed additional sensitivity analyses to assess the robustness of our results. First, we repeated the analyses with the ratio of WC to height as outcome as an alternative to WC. Second, we repeated analyses using the absolute levels of isometric muscle strength and adjusted for body weight and in addition by scaling isometric muscle strength to body weight using the power of 2/3. Finally, because of the high attrition rate due to missing data and loss to follow-up we performed analyses comparing estimates of associations in the sample with complete data on covariates and outcomes (n=332) with the full sample (n=873) with missing values being imputed. We imputed missing values using a multivariate-chained equation imputation approach (‘mi impute chained’ in STATA) including all covariates and respective outomes. We obtained β coefficients and SE’s based on 20 imputed datasets.[22]

All statistical analyses were performed in STATA V.12.1 with $\alpha=0.05$ (two-sided).

RESULTS

Individuals with missing data at baseline (including isometric muscle strength) or follow-up or that were lost to follow-up in 2009/2010 were not different according to age or sex distribution compared with participants in the present study with full data (see online supplementary table S1). However, differences were generally observed in baseline levels of CVD risk factors, lifestyle behaviours and a larger proportion was from parents with only a basic education among individuals lost to follow-up or with missing data. Table 1 shows the baseline characteristics of the study population by tertiles of isometric muscle strength in adolescence. Isometric muscle strength at baseline was negatively associated with BMI, WC, triglyceride, fasting glucose, composite CVD risk z-score and positively associated with intake of fruits and vegetables at baseline (all $p<0.05$). Isometric muscle strength and cardiorespiratory fitness in youth at baseline were modestly associated (figure 1). The sex-adjusted Pearson’s correlation coefficient (r) between isometric muscle strength and cardiorespiratory fitness was 0.34 (95% CI 0.25 to 0.43), $p<0.001$.

Isometric muscle strength in youth was significantly associated with BMI, WC, triglyceride, HDL-C, diastolic BP and composite CVD risk factor score in young adulthood in age, sex and recruitment period-adjusted analyses and in multivariable-adjusted analyses except for WC (table 2). After additional adjustment for cardiorespiratory fitness, associations to BMI, triglyceride, DBP and CVD risk factor score persisted. Furthermore, associations also persisted with adjustment for WC, and using BMI instead of WC did not materially change these results (data not shown).

We also analysed the associations of youth abdominal or back strength relative to body weight separately with CVD risk factors in young adulthood. These analyses were very similar in

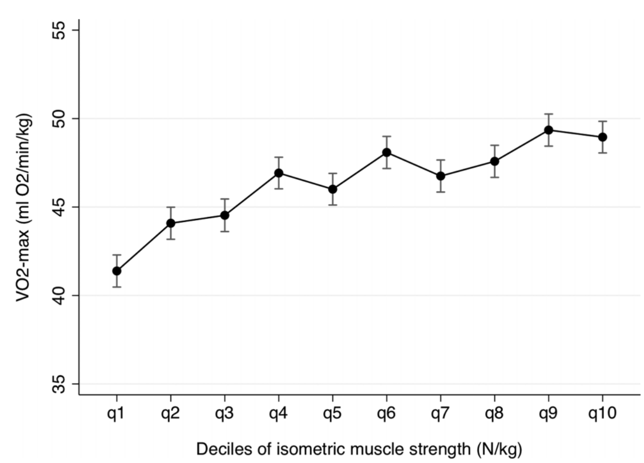

Figure 1 Association of isometric muscle strength and cardiorespiratory fitness in youth at baseline. Estimates are least SE from a sex-adjusted model. Deciles of isometric muscle strength are sex-specific.

Table 2 Isometric muscle strength in youth and cardiovascular risk factors in young adulthood

	Model 1		Model 2		Model 3		Model 4	
	β (95% CI)	p Value	β (95% CI)	p Value	β (95% CI)	p Value	β (95% CI)	p Value
Cardiovascular risk factor								
BMI (kg/m^2)	−0.50 (−0.86 to −0.14)	0.007	−0.45 (−0.81 to −0.08)	0.02	−0.60 (−0.97 to −0.22)	0.002	–	
Waist circumference (cm)	−1.09 (−2.10 to −0.08)	0.03	−0.97 (−2.00 to −0.06)	0.07	−0.93 (−2.00 to 0.13)	0.09	–	
Triglycerides (mmol/l)	−0.10 (−0.16 to −0.04)	0.002	−0.10 (−0.17 to −0.03)	0.004	−0.09 (−0.16 to −0.02)	0.01	−0.09 (−0.16 to −0.02)	0.01
HDL-C (mmol/l)	0.04 (0.01 to 0.07)	0.009	0.03 (0.0004 to 0.06)	0.04	0.02 (−0.01 to 0.05)	0.22	0.02 (−0.01 to 0.05)	0.27
Systolic BP (mm Hg)	−0.88 (−1.85 to 0.08)	0.07	−0.78 (−1.79 to 0.22)	0.13	−0.68 (−1.75 to 0.39)	0.21	−0.73 (−1.80 to 0.34)	0.18
Diastolic BP (mm Hg)	−1.34 (−2.17 to −0.50)	0.002	−1.24 (−2.11 to −0.37)	0.005	−1.22 (−2.15 to −0.29)	0.01	−1.25 (−2.18 to −0.32)	0.009
Glucose (mmol/l)	−0.05 (−0.10 to −0.002)	0.06	−0.05 (−0.10 to 0.003)	0.07	−0.04 (−0.09 to 0.01)	0.14	−0.04 (−0.09 to 0.01)	0.14
Composite CVD risk score (SD)	−0.75 (−1.14 to −0.36)	<0.001	−0.70 (−1.10 to −0.31)	0.001	−0.61 (−1.03 to −0.20)	0.004	−0.47 (−0.79 to −0.14)	0.005

β Coefficient (95% CI) represents change in risk factor in young adulthood per 1 SD (0.17 N/kg) change in isometric muscle strength in adolescence.
Model 1 was adjusted for baseline levels of risk factor, age at baseline, follow-up time, sex and recruitment period.
Model 2 was additionally adjusted for TV watching, parental education level, smoking status, intake of soft drinks, fruit and vegetable intake and family history of CVD.
Model 3 was additionally adjusted for cardiorespiratory fitness.
Model 4 was additionally adjusted waist circumference. Waist circumference was not included in the composite CVD risk score in model 4.
BP, blood pressure; BMI, body mass index; CVD, cardiovascular disease; HDL-C, high-density lipoprotein cholesterol.

magnitude to the mean of abdominal and back isometric strength (normalised to body weight). Furthermore, repeating analyses using the ratio of WC to height, using the absolute levels of isometric muscle strength and adjusting for body weight or by scaling isometric muscle strength to body weight using the power of 2/3 (N/kg$^{2/3}$) all gave fairly similar results (data not shown).

The analysis of isometric muscle strength and incident CVD risk factors is shown in figure 2. During an average of 8 years of follow-up from adolescence, 82, 32, 24, 36 and 55 number of incident cases of general overweight or obesity, abdominal obesity, raised BP, raised triglyceride levels, low HDL-C, respectively, occurred in young adulthood. In multivariable-adjusted analyses including cardiorespiratory fitness, each 1 SD of isometric muscle strength (0.17 N/kg) in youth was significantly associated with 0.59 (95% CI 0.40 to 0.87) lower odds of general overweight or obesity in young adulthood (p=0.007). Furthermore, isometric muscle strength in youth was marginally associated with incident raised BP, raised triglyceride and low HDL-C in young adulthood. Using propensity score matching to adjust for confounding did not materially change these results.

Multivariable-adjusted stratified analyses by sex, follow-up time (6 or 12 years) and cardiorespiratory fitness level are shown in figure 3. We did not see statistical evidence that the association of isometric muscle strength with composite CVD risk factor score were modified by these factors (p>0.1 for all interactions); however, stratified analyses indicated that associations were attenuated among individuals with low cardiorespiratory fitness (p=0.15 for interaction). Combined association of cardiorespiratory fitness and isometric muscle strength using sex-specific tertiles of fitness and strength, respectively, also

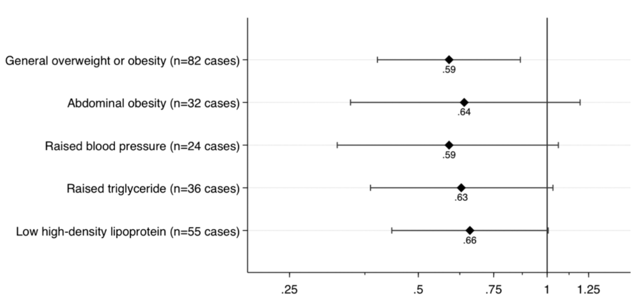

Figure 2 Isometric muscle strength in adolescence and risk of incident general overweight/obesity, abdominal obesity, raised blood pressure, raised triglyceride and low high-density lipoprotein in young adulthood. Estimates are ORs with 95% CI from logistic regression models adjusted for baseline levels of respective risk parameter (eg, body mass index for general overweight), age at baseline, follow-up time, sex, recruitment period, cardiorespiratory fitness, TV watching, parental education level, smoking status, intake of soft drinks, fruit and vegetable intake and family history of cardiovascular disease. Numbers in brackets are incident cases of respective outcomes.

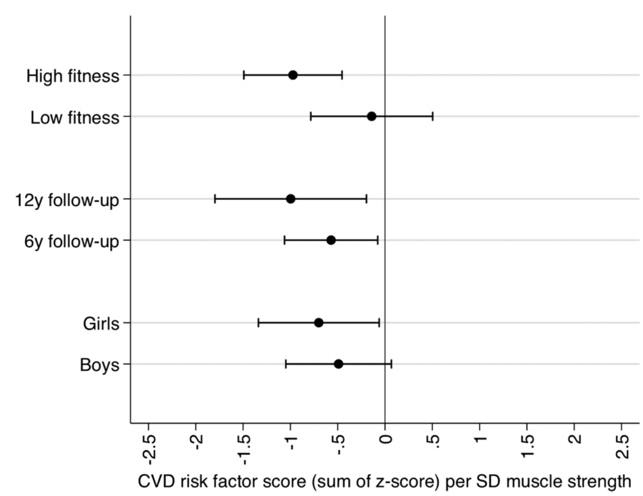

Figure 3 Isometric muscle strength in youth and composite cardiovascular risk factor score in young adulthood stratified by cardiorespiratory fitness (below and above the median, sex-specific), follow-up time (6 or 12 years) and sex. Estimates are β coefficients (composite cardiovascular disease (CVD) risk factor score in young adulthood per SD of isometric muscle strength in youth) from multivariable model adjusted for baseline levels of CVD risk score, age at baseline, follow-up time, sex, recruitment period, cardiorespiratory fitness, TV watching, parental education level, smoking status, intake of soft drinks, fruit and vegetable intake and family history of CVD. Median of low fitness boys=46.5, girls=39.2; high fitness boys=54.7, girls=45.6.

indicated no interaction between strength and fitness on composite CVD score (p=0.22 for interaction) and suggested an additive effect of isometric muscle strength and fitness in youth on CVD risk in young adulthood. Participants being in the third sex-specific tertile of both fitness and strength had lowest composite CVD risk score in young adulthood (−1.42 SD (95% CI −2.67 to −0.17) compared with participants being in the first tertile of both fitness and strength).

Results from associations based on non-imputed samples (n=332) were fairly similar to imputed samples (see online supplementary table S2).

DISCUSSION

Results from this prospective population-based study suggest that greater isometric muscle strength of the abdomen and back in youth is associated with lower levels of CVD risk factors in young adulthood. These inverse associations were independent of cardiorespiratory fitness, adiposity and other sociodemographic and lifestyle factors. Our study supports including a specific recommendation for activities that increase muscle strength as part of the guidelines for PA in youth for primordial prevention of CVD risk later in life.

To the best of our knowledge this is the first study reporting independent associations of muscle strength with CVD risk factors among adolescents followed into adulthood. A previous study among children followed into adolescence has shown that improvement in handgrip strength during follow-up was associated with favourable changes in BP, lipid levels and adiposity independent of cardiorespiratory fitness.[23] A few prior cross-sectional studies among children or adolescents have reported similar findings. Two population-based studied among European children and adolescents have reported that muscle strength were associated with clustered metabolic risk independent of cardiorespiratory fitness.[24 25] Our results are also generally in line with findings from observational studies among adults. A report from the Aerobics Centre Longitudinal Study found that high dynamic muscle strength of the lower and upper body was associated with a decreased risk of premature mortality independent of cardiorespiratory fitness in men.[4] Furthermore, in the Health Professionals Follow-up Study men participating in weight training had a lower risk of CHD independent of other PA.[5] Other studies among adults have also reported inverse associations of muscle strength with premature mortality, but many have not adjusted for cardiorespiratory fitness.[26–29] Because we, and others, have reported that isometric muscle strength and cardiorespiratory fitness are modestly related, confounding by fitness is likely not trivial.

Numerous experimental studies support the biological plausibility of our findings. A number of small-scale randomised studies in overweight youth have provided evidence that muscle-strengthening exercise alone is beneficial for improving CVD risk factor levels.[30–33] Similarly, randomised trials among adults have shown beneficial effects of resistance training on BP, adiposity, glycemic control and triglyceride levels.[34–36] Because initiation in muscle-strengthening activities is strongly related to gains in muscle strength in youth,[9] these observations support our study and suggests that low muscle strength is causally related to development of unfavourable levels of CVD risk factors.

Our assessments of maximal isometric muscle strength of the abdomen and back were based on an easy, simple and fast testing procedure. Although previous studies have reported moderate-to-strong correlation between isometric and dynamic muscle strength,[37] further studies are warranted to confirm that assessment of muscle strength, using similar or alternative methods including different muscle groups and types of strength measures in predicting future CVD health outcomes independent of cardiorespiratory fitness. In addition, while the isometric muscle strength assessment procedures are very reliable in adults, we did not evaluate reliability of the tests in youth, which remains to be determined.

Strengths of this study include the prospective design, the standardised test for cardiorespiratory fitness and isometric muscle strength. Furthermore, the detailed collection of lifestyle factors, sociodemographic factors and other covariates allowed adjustment for several potential confounders. A number of possible limitations should also be considered. Although we observed substantial magnitudes of associations for isometric muscle strength, the sample size for the study was modest and the number of incident cases of CVD risk factor in young adulthood was not large in the logistic regression models. As a consequence the CIs for these analyses were wide, however, these analyses were supported by similar patterns in linear models. Although the composite CVD risk factor score has been widely used there are limitations to its use. Individual CVD risk factors are weighted equally in the composite score, is population-specific, and the predicate validity in youth for clinical health outcomes in adulthood remains unknown. Furthermore, as our study was observational, there will always be a possibility of unknown and residual confounding. Finally, the high attrition rate may have affected the generalisability of our findings and precluded us from adequately powered subgroup analysis. Since associations were fairly similar in imputed and non-imputed samples, this provides us some confidence that the results are not explained by selection bias.

In conclusion, greater isometric muscle strength of the abdomen and back in youth was associated with lower levels of CVD risk factors in young adulthood independent of cardiorespiratory fitness and other potential confounding factors. These results support a specific emphasis on participation in muscle-strengthening activities for primordial prevention of CVD risk in accordance to the current guidelines for PA in youth. Given the major global public health burden of CVD our results highlight the need to further investigate the role of participation in resistance training activities in other populations and in randomised trails in children and youth.

What this study adds

- This study suggests that greater isometric muscle strength of the abdomen and back in youth is associated with lower levels of cardiovascular risk factors in young adulthood independent of cardiorespiratory fitness, sociodemographic and lifestyle factors.

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Contributors AG collected the data, carried out the initial analyses, drafted the initial manuscript and approved the final manuscript as submitted. MR-L, NCM and PLK collected the data, reviewed and revised the manuscript, and approved the final manuscript as submitted. KF conceptualised and designed the study, collected the data, reviewed and revised the manuscript, and approved the final manuscript as submitted. SB and LBA conceptualised and designed the study, reviewed and revised the manuscript and approved the final manuscript as submitted.

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Competing interests None.

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