Factors associated with muscular fitness phenotypes in Australian children: A cross-sectional study

Short running title: Factors associated with childhood muscular fitness

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Abstract

To help inform strategies aimed at increasing muscular fitness levels, we examined factors associated with childhood muscular fitness (strength and power) that preceded the recently observed secular decline. Data were available from a nationally representative sample of Australian children aged 7–15 years in 1985 (n=8469). Muscular fitness measures included strength (right and left grip, shoulder extension and flexion, and leg strength measured by dynamometers as a combined strength score) and power (standing long jump distance, cm). Anthropometric (adiposity, fat-free mass), cardiorespiratory fitness (CRF), flexibility, speed capability, physical activity (individual and parental), dietary quality and intake (fruit, vegetable, protein) and sociodemographic (area-level socioeconomic status (SES), school type) data were available. Statistical analyses included sex-stratified linear regression. Of all examined factors, measures of adiposity, fat-free mass, CRF, flexibility and speed capability were associated with muscular fitness at levels that met Cohen's threshold for important effects (r-squared=0.02 to 0.28). These findings highlight the multifactorial relationship between muscular fitness and its determinants. Collectively, these factors were powerful in explaining muscular strength (females: r-squared=0.32; males: r-squared=0.41) and muscular power (females: r-squared=0.36; males: r-squared=0.42). These findings highlight modifiable and environmental factors that could be targeted to increase childhood muscular fitness.

Keywords: Muscle Strength, Muscular Power, Epidemiology, Cohort, Children

Introduction

Muscular fitness incorporates the phenotypes of strength, power and endurance (Artero et al., 2011). The role muscular fitness plays in general health and chronic disease is becoming increasingly recognised, with previous research highlighting low muscular fitness levels as an independent risk factor for poor cardiometabolic health outcomes and all-cause mortality in adults (Jurca et al., 2005; Katzmarzyk and Craig, 2002). Recently, the benefits of high childhood muscular fitness on adiposity levels, skeletal health, self-esteem and cardiovascular risk factors have been summarised (Ortega, Ruiz, Castillo, & Sjostrom, 2008; Smith et al., 2014) and the association of low childhood muscular fitness levels with increased risk for poor adult health outcomes has been reported (Fraser et al., 2018; Fraser et al., 2016; Grøntved et al., 2015). In recognition of the purported health benefits of muscular fitness in preventing chronic disease, the World Health Organisation physical activity guidelines have been revised to incorporate activities aimed at strengthening muscle and bone at least twice per week, in addition to aerobic activities, in both children and adults (World Health Organization, 2010).

Globally, childhood muscular fitness levels have declined between the mid 1980s and early 2000s (Tomkinson, 2007) and in Australia, declines were observed between 1985 and 2015 (Fraser et al., 2019; Hardy, Merom, Thomas, & Peralta, 2018). In 1985, the health and fitness of a nationally representative sample of Australian school children was examined as part of the Australian Schools Health and Fitness Survey (ASHFS). The ASHFS provides an opportunity to examine correlates of childhood muscular fitness preceding the secular decline. To develop effective interventions aimed at increasing childhood muscular fitness and reversing this decline, a better understanding of the factors associated with higher muscular fitness is needed. Analysing the ASHFS data can help address this research gap as it was from a period where muscular fitness levels were greater than they are currently. Modifiable (e.g. adiposity, physical activity behaviours, dietary intake) and environmental (e.g. socioeconomic position) correlates of muscular fitness have been identified (Grøntved et al., 2013; Jimenez Pavon et al., 2010; Martinez-Gomez et al., 2011; Moliner-Urdiales et al., 2011; Neville, McKinley, Murray, Boreham, & Woodside, 2014). However, past studies have looked at only one or two factors, examined data collected during the secular decline period or had relatively small sample sizes. A comprehensive analysis into the association between a wide range of factors and muscular fitness levels within one large cohort of children preceding the secular decline in muscular fitness levels, is lacking. Using data from the ASHFS we aimed to identify modifiable and environmental factors associated with muscular fitness in Australian children.

Materials and methods

Participants

In 1985, the ASHFS collected data on a nationally representative sample of 8,498 Australian children aged 7–15 years. Additional details on the sampling strategy have been published elsewhere (Dwyer and Gibbons, 1994). Children of all ages had their standing long jump measured (n=8,459), whilst a subset of children aged 9, 12 and 15 years had muscular strength measures taken (n=2,745). Anthropometric, cardiorespiratory fitness (CRF), physical activity, dietary and sociodemographic data were also collected. Children who provided a measure of muscular strength or had their standing long jump measured were included in analyses (n=8,469). Parents provided consent and students provided assent prior to inclusion into the ASHFS. The State Directors General of Education approved the study.

Muscular fitness

Muscular strength was tested by maximum voluntary contraction using isometric dynamometers (Smedley's Dynamometer, TTM, Tokyo, Japan) at five different sites: right and left grip, shoulder flexion and extension, and leg. Each participant was allowed one attempt at grip strength and two attempts at all other tests. The maximum result from each site was used in analyses. Right and left grip strength was measured by gripping the hand dynamometer with maximum force with one hand, whilst the dynamometer rested on the opposite shoulder. To measure shoulder flexion and extension, participants held the dynamometer in front of their chest with both hands parallel to the ground and pulled (extension) or pushed (flexion) with maximum effort. Leg strength was measured by participants standing on a leg-back dynamometer with flat feet, a straight back and with their body flat against a wall behind them. With an overhand grip, participants then held a bar with straight arms whilst they flexed their knees until an angle of 115° was reached. At this point, a chain was attached from the dynamometer to the bar and participants slid their body up the wall whilst pulling the bar as far upwards as possible (Fraser, et al., 2016). The five strength measures were combined into a single muscular strength score using principal component analysis, where the first principal component of each strength measure was obtained (Fraser, et al., 2016; Quan et al., 2014). Muscular power was measured from a standing long jump test, where a two-footed take-off and landing was required. The longest distance (cm) recorded from the two attempts was used in analyses. Measures of muscular fitness not attributable to body mass were created by regressing each muscular fitness measure on body mass and using the residuals (Fraser, et al., 2016; Quan, et al., 2014). Each muscular fitness measure was age- and sex-standardised.

Adiposity and fat-free mass

Body mass index (BMI) was calculated as body mass (kg) divided by height (m) squared. Body mass was measured using regularly calibrated scales to the nearest 0.5 kg and height was measured to the closest 0.1 cm using a KaWe height tape (KaWe Kirchner & Wilhelm, Aspeg, Germany). BMI values were used to categorise participants as normal weight, overweight or obese according to Cole's international cut-points for children (Cole, Bellizzi, Flegal, & Dietz, 2000). Using a constant tension tape, waist circumference was measured to the nearest 0.1 cm at the level of the umbilicus. Body mass and estimates of percentage body fat derived from the sum of four skin folds, were used to calculate fat-free mass (Durnin and Womersley, 1974). Holtain calipers (Holtain, Crymych, UK) were used to measure triceps, biceps, subscapular, and suprailiac skinfolds to the nearest 0.1 mm for children aged 9, 12 and 15 years (n=2777). Using age-specific regression estimates (Durnin and Womersley, 1974), the log of the sum of skinfolds were used to calculate body density and fat percentage. The Siri formula was used to calculate body fat from body density (Siri, 1956), and fat-free mass was estimated as the difference between total body mass and fat mass.

Cardiorespiratory fitness

For children aged 9, 12 and 15 years (n=2622), CRF was measured as physical work capacity at a heart rate of 170 beats per minute (PWC_{170}) using a Monark 818E bicycle ergometer (Monark Exercise AB, Vansbro, Sweden). This sub-maximal test included three successive 3-minute workloads that incrementally increased resistance. In the final minute of each workload, heart rate and watts were recorded, plotted and extrapolated to provide PWC_{170}. As the absolute work load achieved in these tests is a function of muscle mass (Buskirk and Taylor, 1957), we created measures of PWC_{170} not attributable to fat-free mass (Quan, et al., 2014). CRF was additionally measured as time to complete a 1.6 km run (all children), with maximal oxygen consumption (VO_2 max) estimated using a generalised equation proposed and validated by Cureton et al (Cureton, Sloniger, O'Bannon, Black, & McCormack, 1995).

Flexibility and speed capability

Flexibility was measured using a sit and reach test. Participants were seated with straight legs and the soles of both feet flat against the front of a sit and reach box. Participants reached forward as far as they could. After holding this position for three seconds, a research technician recorded the distance reached at the level of the participants' fingertip to the nearest complete centimetre. Positive results suggest children could reach past their toes and negative results suggest children could not reach their toes. This test was performed twice, and the best result was used in analyses. Speed capability was measured as time to complete a 50-meter run with times recorded to the nearest 0.01 of a second. As speed capability was measured in seconds, a lower run time reflects a better result.

Physical activity

Children aged 9 years and over were administered a questionnaire relating to sport and exercise participation and their parents exercise habits. Children completed this questionnaire in groups of four under the supervision of trained assessors. This questionnaire was developed in the early 1980s specifically for this survey. Self-reported physical activity participation has been shown to be reported at acceptable levels (retest-reliability: 0.60-0.98) for children aged 9 years and older (Sallis and Saelens, 2000). The levels of physical activity self-reported in ASHFS were consistent with those observed in other cohorts (Booth, Okely, Chey, Bauman, & Macaskill, 2002; Trost et al., 1996) and demonstrated similar positive relationships with CRF (r=0.2) to those observed for other self-reported measures (Trost, 1998). Physical activity levels were categorised based on responses to the questionnaire (Cleland, Dwyer, & Venn, 2008). ‘School physical activity’ was defined as the sum of school physical education and school sport. ‘Non-school physical activity’ was defined as the sum of active commuting and leisure time physical activity. The sum of all individual physical activity domains was used as an estimate of ‘total physical activity’ (Cleland, et al., 2008). Children reported parental exercise habits by being asked “Does your father exercise regularly (2 or more times a week)?” and “Does your mother exercise regularly (2 or more times a week)?”. Parental exercise was categorised as ‘Both parents inactive’, ‘Father active only’, ‘Mother active only’ or ‘Both parents active’.

Dietary quality and intake

Children aged 10-15 years (n=5024) completed a 24-hour food diary. In small groups, students were shown how to measure and record their intake by trained data collectors. A database compiled for the study was used to calculate nutrient intake. Total daily intake of protein in grams and total daily serves of core food groups and discretionary foods (those that are not essential for a healthy diet and are high in saturated fat, sugar, salt or alcohol. For example, ice-cream, chocolate, soft drinks) were calculated from gram weight or kilojoule content. For fruit and vegetable intake, responses were grouped into “1 serve or less”, “2-3 serves” and “4 or more serves”. Total daily serves of protein were calculated by summing the daily serves of meat and alternatives (lean and non-lean) with the daily servings of dairy and alternatives. Daily protein serves were grouped as “2 serves or less”, “3-4 serves” and “5 or more serves”. A dietary guideline index (DGI) score was calculated from the sum of nine individual dietary component scores (Wilson et al., 2019). Each individual component was scored from 0 to 10, with the exception of discretionary food intake which was scored from 0 to 20. The DGI score was based on compliance with the age and sex specific recommendations in the 2013 Australian Dietary Guidelines (National Health and Medical Research Council, 2013). Larger DGI values reflect a healthier diet.

Socioeconomic position

For children aged 9–15 years (n=6277), area-level socioeconomic status (SES) was estimated using the Australian Bureau of Statistics Socio-economic Index for Areas (SEIFA) and 1981 census data. Area-level SES was categorised as low, medium-low, medium-high and high. Children attended state (public or non-fee paying), Catholic (private or fee-paying) or independent (private or fee-paying) schools.

Statistical analyses

All statistical analyses were performed using Stata (Version 15.0, StataCorp, College Station, Texas).

Demographics

Characteristics were sex-stratified and presented as mean (standard deviation) or median (interquartile range) values for continuous variables, and percentages (number of participants) for categorical variables.

Factors associated with muscular fitness

Factors associated with age- and sex-standardised muscular fitness phenotypes were identified using sex-stratified univariable linear regression adjusted for age. Analyses were stratified by sex as significant ($p \leq 0.05$) sex interactions were observed for multiple factors. All covariates were appropriately scaled, and beta coefficients represent the estimated difference in muscular fitness phenotypes per one-unit increase in a continuous variable from its mean. For each regression model, r-squared values were presented and interpreted as a measure of effect size. R-squared values greater than 0.02 suggest the association meets Cohen's threshold for an important effect (Cohen, 1988). Factors that were significantly ($p \leq 0.05$) associated with muscular fitness phenotypes at a univariable level were included within multivariable models. Where two or more factors in the same category (categories: adiposity, CRF, individual physical activity) had a p-value ≤0.05, the factor with the greatest r-squared value was carried forward into final multivariable models.

Results

Demographics

Participant characteristics are presented in Table 1. On average, males had higher muscular fitness and CRF, and were taller and heavier, compared with females. Females had higher sum of skinfolds and BMI compared with males.

Factors associated with muscular fitness

Table 2 displays associations between single factors and the combined muscular strength score. Continuous BMI (females), BMI categories (both sexes), waist circumference (females), sum of skinfolds (both sexes) and speed capability (both sexes) were inversely associated with muscular strength. The positive association between continuous BMI and muscular strength for males (p=0.28) is explained by the scaling of BMI (quadratic). The association with muscular strength differs per one-unit increase in BMI from its 25^{th} (β=0.13, 95% CI=0.08 to 0.19, r-squared=0.08, p<0.001), 50^{th} (β=0.05, 95% CI=0.01 to 0.10, r-squared=0.08, p=0.02) and 75^{th} (β=–0.06, 95% CI=–0.09 to –0.03, r-squared=0.08, p<0.001) quartile. A negative association was present at higher levels of BMI and at all examined percentiles upon adjustment for other modifiable factors including fat-free mass (data not shown). Fat-free mass, CRF, flexibility (both sexes), school, non-school (females) and total weekly physical activity levels (both sexes) were positively associated with muscular strength. Having two active parents was associated with higher muscular strength compared with having no active parents (females). Greater intakes of fruit, vegetable and protein were positively associated with muscular strength (males) and having 3 to 4 serves of protein per day was associated with higher muscular strength compared with having 2 serves or less (females). Compared with low area-level SES and attending a state school, higher area-level SES and attending an independent (fee paying) school were positively associated with muscular strength (both sexes).

Factors associated with muscular power are presented in Table 3. Measures of adiposity and speed capability (measured in seconds, with higher run time reflecting lower speed capability) were inversely associated with muscular power (both sexes). Fat-free mass (males), CRF, flexibility and physical activity behaviours (both sexes) were all positively associated with muscular power. Compared with having no active parents, having two active parents was associated with higher muscular power (females). Higher diet quality and greater daily intake of fruit, vegetable and protein were associated with greater muscular power (both sexes). Area-level SES was positively associated with muscular power (both sexes) and attending a Catholic school (males) and independent school (both sexes) were associated with greater muscular power, compared with attending a state school.

Factors that remained associated with muscular fitness phenotypes in final multivariable models are presented in Table S1 (muscular strength) and Table S2 (muscular power). Fat-free mass, flexibility (both sexes) and CRF (females) remained positively associated with muscular strength. Negative associations remained for adiposity and speed capability (both sexes). Attending a Catholic school was associated with lower muscular strength and attending an independent school was associated with greater muscular strength, compared with attending a state school (males). Factors that remained positively associated with muscular power included flexibility, area-level SES (both sexes), fat-free mass (males) and CRF (females). Attending a Catholic (males) or an independent school (both sexes) was associated with greater muscular power, compared with attending a state school. Negative associations were retained for adiposity and speed capability (both sexes).

Discussion

This study identified the association between modifiable and environmental factors and childhood muscular fitness levels. Of all examined factors, measures of adiposity, fat-free mass, CRF, flexibility and speed capability were associated with muscular fitness at a level that met Cohen’s threshold for important effects. These findings highlight the multifactorial relationship of muscular fitness and indicators of it. These disjoint signals individually meet Cohen’s threshold for important effects, but collectively are powerful in explaining muscular strength (r-squared=0.32 to 0.41) and muscular power (r-squared=0.36 to 0.42). These findings could help inform future interventions aimed at increasing childhood muscular fitness by highlighting factors associated with muscular fitness preceding the recently observed secular decline.

Past research has reported measures of adiposity to be associated with muscular fitness levels (Moliner-Urdiales, et al., 2011). Similar to trends found previously (Milliken, Faigenbaum, Loud, & Westcott, 2008), adiposity was negatively associated with measures of muscular fitness that were not attributable to body mass, with sum of skinfolds being the adiposity measure most strongly associated with muscular fitness (r-squared=0.06 to 0.10).

Low adiposity levels could reflect healthier and more physically active lifestyles, which combine to associate with muscular fitness levels. A key component of fat-free mass is muscle mass, and greater muscle mass could influence muscular fitness performance. Fat-free mass was positively associated with muscular strength for both males and females and with muscular power for males. Positive associations between CRF and muscular fitness have been highlighted previously (Fang, Burns, Hannon, & Brusseau, 2016; Grøntved, et al., 2013). In univariable models, CRF was associated with muscular fitness in males and females (r-squared=0.08 to 0.13). Within multivariable models presented in our study, positive associations were present for females only. These associations could suggest aerobically fit females are also participating in muscular fitness activities, whereas a more heterogenous relationship could be present for males where an aerobically fit male is not necessarily a muscular fit male. In a recent systematic review, measures of physical activity, particularly vigorous physical activity, were positively associated with muscular fitness (Smith et al., 2019). Physical activity was positively associated with muscular strength and power in our study, although associations did not reach Cohen's threshold for important effects.

Previously, flexibility correlated positively with muscular strength (Milliken, et al., 2008). Greater flexibility could result in an increased ability to move joints and muscles in a full range of motion which could benefit muscular fitness performance tests. Further, physical activities that support the development of muscular strength and power might also support greater flexibility. Our results showed flexibility to be associated with muscular strength and power (r-squared=0.05 to 0.06). The 50-metre run time, a measure of speed capability, was shown to be the factor most strongly associated with muscular strength and power (r-squared=0.21 to 0.28). These inverse associations, where a longer run time (i.e. lower speed capability) was associated with lower muscular fitness, were not surprising given the 50-metre run requires a rapid burst of power that is only sustained for a few seconds.

Measures of dietary quality and intake were associated with muscular fitness in univariable models, although associations did not reach Cohen's threshold for important effects. The association between greater protein intake and higher muscular fitness could reflect greater protein intake resulting in the potential formation of more muscle. Higher levels of muscular fitness could also reflect healthy dietary choices and greater overall diet quality. Further, nutritional deprivation contributes to poorer muscle function. Hand grip, a common measure of overall muscular strength, has been previously identified as a marker of nutritional status (Norman, Stobaus, Gonzalez, Schulzke, & Pirlich, 2011). However, the association between diet and muscular fitness was not statistically significant in multivariable models. This may suggest lower adiposity levels and less sedentary lifestyles could explain the positive association between dietary intake and muscular fitness.

Environmental factors including area-level SES and school type were shown to be associated with muscular fitness in univariable models, although associations did not reach Cohen's threshold for important effects. In multivariable models, higher area-level SES remained positively associated with muscular power for both sexes and compared with attending a state school, attending an independent school was associated with greater muscular strength for males and greater muscular power for both sexes. However, for males, attending a catholic school was associated with decreased muscular strength and increased muscular power, compared with attending a state school. It is unclear why these results vary. For the most part, these associations highlight the link between SES and muscular fitness, an association supported by previous research (Jimenez Pavon, et al., 2010). Higher SES could reflect greater opportunity and increased availability to facilities which could promote increased participation in muscular fitness activities.

We acknowledge that childhood muscular fitness levels have declined between the mid 1980s and 2000s (Fraser, et al., 2019; Hardy, et al., 2018; Tomkinson, 2007). This historical sample provides the opportunity to better understand modifiable and environmental factors that were associated with childhood muscular fitness preceding the decline. Although it is plausible that some factors associated with childhood muscular fitness have remained consistent (e.g. genetic), others may have changed (food environment, physical activity opportunities/demands). Whether our associations would be the same in a contemporary cohort requires additional research. This study was limited by the cross-sectional design. We therefore cannot determine the direction of effect. Despite this, these results suggest a wide range of factors are associated with childhood muscular fitness levels. Additional study limitations include the use of self-reported dietary and physical activity data. Muscular fitness has both a behavioural and genetic component (Frederiksen and Christensen, 2003), therefore further research examining the association between genetics and muscular fitness is required. Although historic, ASHFS is a unique survey in which a large nationally representative sample of Australian school children provided a wide range of novel data. A notable strength of this study was the use of reliable and valid field-based tests to measure muscular fitness (Artero, et al., 2011). Grip strength, a key component of our combined muscular strength score, and the standing long jump, our measure of muscular power, demonstrate very good test-retest reliability (Ortega et al., 2008) and good construct validity (Milliken, et al., 2008). Given the breadth of variables available, we had the ability to examine the association between a range of modifiable and environmental factors and muscular fitness levels in children.

The ASHFS was conducted to provide a benchmark for the health and fitness of Australian children. Future research is required to repeat these associations using a contemporary cohort and identify whether factors associated with childhood muscular fitness have changed alongside the decline in muscular fitness levels. Furthermore, our results are hypothesis generating for future interventions aimed at increasing childhood muscular fitness, as they highlight potential modifiable and environmental factors these interventions could target. Lastly, as research continues to highlight the long-term health benefits of childhood muscular fitness (Fraser, et al., 2018; Fraser, et al., 2016; Grøntved, et al., 2015), our findings help to better understand the interrelationship of childhood factors and provide insight into potentially important covariates.

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Disclosure of interest

The authors report no conflict of interest.

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Tables

Table 1. Characteristics of participants.

		Sex	
		Male	Female
Characteristic	n	Statistic	Statistic
Age, years	8469	11.0 (2.6)	10.8 (2.5)
Right grip strength, kg	2793	25.2 (10.2)	21.0 (6.8)
Left grip strength, kg	2793	24.8 (10.0)	20.1 (6.4)
Shoulder flexion, kg	2756	20.2 (13.7)	18.0 (9.0)
Shoulder extension, kg	2757	17.4 (9.4)	13.9 (6.2)
Leg strength, kg	2783	114.8 (55.7)	83.3 (33.0)
Combined strength score	2745	–0.01 (1.63)	0.01 (1.62)
Standing long jump, cm	8459	150.5 (30.6)	135.6 (25.0)
Body mass, kg	8469	40.2 (13.6)	39.4 (12.4)
Height, cm	8465	146.7 (16.3)	144.8 (14.4)
BMI, kg/m^2	8465	18.1 (2.8)	18.3 (3.0)
Waist circumference, cm	8464	64.5 (8.9)	62.6 (8.2)
Sum of skinfolds, mm	2777	32.3 (17.7)	43.7 (19.4)
Fat-free mass, kg	2777	35.1 (10.0)	31.9 (7.3)
1.6 km run, mins	7876	8.4 (1.7)	10.1 (1.8)
PWC_{170}, watts	2645	107.3 (42.1)	78.9 (26.1)
Estimated VO_2 max, ml/kg/min	7863	50.2 (4.3)	44.5 (3.8)
Sit and reach, cm	8443	2 (–2, 6)	7 (2, 11)
50m run, sec	8057	9.0 (1.1)	9.5 (1.0)

School physical activity, mins/week	5643	120 (80–200)	120 (80–180)
Non–school physical activity, mins/week	5672	240 (115–480)	185 (90–360)
Total weekly physical activity, mins/week	6390	356 (200–620)	290 (165–500)
Parental exercise	5909		
Both parents inactive		43.4 (1301)	40.9 (1191)
Father active only		20.9 (627)	19.3 (563)
Mother active only		17.3 (518)	18.3 (532)
Both parents active		18.4 (550)	21.5 (627)
Dietary Guidelines Index	5024	44.7 (12.1)	43.3 (11.7)
Fruit intake	5024		
1 serve or less		61.7 (1562)	60.6 (1510)
2–3 serves		23.7 (599)	26.2 (654)
4 or more serves		14.6 (369)	13.2 (330)
Vegetable intake	5024		
1 serve or less		45.3 (1147)	48.4 (1208)
2–3 serves		28.9 (732)	32.7 (815)
4 or more serves		25.7 (651)	18.9 (471)
Protein, grams	5024	82.4 (33.7)	63.8 (23.6)
Protein intake	5024		
2 serves or less		37.4 (945)	52.7 (1313)
3–4 serves		37.0 (935)	34.6 (863)
5 or more serves		25.7 (650)	12.8 (318)

Socioeconomic position	6277		
Low		9.7 (309)	8.8 (271)
Medium-Low		38.5 (1228)	38.5 (1189)
Medium-High		28.6 (913)	28.5 (881)
High		23.2 (740)	24.2 (746)
School type	8469		
State		75.1 (3228)	74.9 (3125)
Catholic		19.2 (824)	20.3 (845)
Independent		5.7 (246)	4.8 (201)

Statistics are mean (standard deviation) or median (interquartile range) for continuous variables or percentages (n) for categorical variables. Percentages may not total 100 due to rounding. Abbreviations: BMI, body mass index; PWC_{170}, physical work capacity at a heart rate of 170 beats per minute; SES, socioeconomic status; VO_2 max, maximal oxygen consumption.

Table 2. Associations between modifiable and environmental factors and the combined muscular strength score for males and females, adjusted for age.

	Males				Females			
Characteristic	n	Beta coefficient (95% CI)*	r-squared	*p-value*	n	Beta coefficient (95% CI)*	r-squared	*p-value*
Adiposity and fat-free mass								
BMI, kg/m^2	1388	0.02 (–0.02, 0.06)	0.08	*0.28*	1356	–0.04 (–0.08, –0.00)	0.03	*0.05*
BMI categories								
Normal	1230	REF	0.06	REF	1190	REF	0.03	REF
Overweight	132	–0.72 (–1.01, –0.44)		*<0.001*	144	–0.59 (–0.87, –0.32)		*<0.001*
Obese	26	–2.41 (–3.03, –1.80)		*<0.001*	22	–1.87 (–2.55, –1.20)		*<0.001*
Waist circumference, per 10 cm	1389	–0.08 (–0.21, 0.05)	0.07	*0.23*	1355	–0.43 (–0.59, –0.27)	0.03	*<0.001*
Sum of skinfolds, per 10 mm	1378	–0.29 (–0.34, –0.25)	0.10	*<0.001*	1345	–0.21 (–0.26, –0.17)	0.06	*<0.001*
Fat-free mass, per 1 kg	1378	0.08 (0.06, 0.10)	0.04	*<0.001*	1345	0.07 (0.05, 0.09)	0.04	*<0.001*
Cardiorespiratory fitness								
1.6 km run, per 1 min	1310	–0.29 (–0.35, –0.24)	0.08	*<0.001*	1237	–0.33 (–0.38, –0.27)	0.09	*<0.001*
PWC_{170}, per 10 watts	1312	0.15 (0.12, 0.19)	0.05	*<0.001*	1262	0.27 (0.20, 0.34)	0.05	*<0.001*
Estimated VO_2 max, per 1 ml/kg/min	1309	0.11 (0.09, 0.13)	0.08	*<0.001*	1237	0.09 (0.07, 0.11)	0.06	*<0.001*
Flexibility and speed capability								
Sit and reach, per cm	1385	0.07 (0.05, 0.08)	0.06	*<0.001*	1351	0.06 (0.04, 0.07)	0.06	*<0.001*
50m run, per second	1322	–0.91 (–1.06, –0.75)	0.22	*<0.001*	1271	–0.94 (–1.04, –0.83)	0.21	*<0.001*
Physical activity								
School physical activity, per 60 mins/week	1183	0.04 (–0.01, 0.10)	0.00	*0.10*	1142	0.05 (0.01, 0.09)	0.01	*0.02*
Non–school physical activity, per 60 mins/week	1227	0.01 (–0.01, 0.02)	0.00	*0.44*	1158	0.03 (0.01, 0.04)	0.01	*0.001*

Total weekly physical activity, per 60 mins/week	1363	0.02 (0.01, 0.04)	0.01	*0.008*	1338	0.04 (0.02, 0.06)	0.02	<*0.001*
Parental exercise								
Both parents are inactive	553	REF	0.00	REF	546	REF	0.02	REF
Father active only	252	0.09 (–0.16, 0.33)		*0.49*	228	0.14 (–0.11, 0.39)		*0.26*
Mother active only	223	0.02 (–0.23, 0.27)		*0.90*	207	0.22 (–0.04, 0.47)		*0.10*
Both parents are active	227	0.15 (–0.10, 0.40)		*0.24*	276	0.57 (0.34, 0.81)		<*0.001*
Dietary quality and intake								
Dietary Guidelines Index, per 10 units	810	0.05 (–0.05, 0.16)	0.01	*0.29*	812	0.07 (–0.03, 0.16)	0.00	*0.16*
Fruit intake								
1 serve or less	503	REF	0.01	REF	491	REF	0.00	REF
2–3 serves	189	0.09 (–0.19, 0.36)		*0.53*	209	0.05 (–0.21, 0.31)		*0.71*
4 or more serves	118	0.36 (0.03, 0.68)		*0.03*	112	0.10 (–0.23, 0.43)		*0.55*
Vegetable intake								
1 serve or less	358	REF	0.01	REF	395	REF	0.00	REF
2–3 serves	234	0.03 (–0.24, 0.30)		*0.84*	254	0.06 (–0.20, 0.31)		*0.66*
4 or more serves	218	0.41 (0.13, 0.68)		*0.004*	163	0.16 (–0.13, 0.46)		*0.28*
Protein, total daily intake per 10 grams	810	0.05 (0.02, 0.08)	0.01	*0.004*	812	0.04 (–0.00, 0.09)	0.00	*0.06*
Protein intake								
2 serves or less	269	REF	0.00	REF	424	REF	0.01	REF
3–4 serves	309	0.01 (–0.25, 0.28)		*0.92*	275	0.37 (0.13, 0.62)		*0.003*
5 or more serves	232	0.20 (–0.09, 0.49)		*0.18*	113	0.06 (–0.28, 0.39)		*0.74*
Socioeconomic position								
Area–level SES								
Low	125	REF	0.01	REF	118	REF	0.01	REF
Medium–low	508	0.18 (–0.13, 0.50)		*0.26*	520	0.36 (0.04, 0.69)		*0.03*

Medium–high	379	0.16 (–0.17, 0.49)		*0.33*	368	0.23 (–0.10, 0.57)		*0.18*
High	326	0.46 (0.13, 0.80)		*0.006*	314	0.45 (0.11, 0.79)		*0.01*
School type								
State	1037	REF	0.01	REF	1026	REF	0.00	REF
Catholic	268	–0.12 (–0.35, 0.09)		*0.25*	272	0.08 (–0.14, 0.29)		*0.49*
Independent	84	0.55 (0.19, 0.91)		*0.003*	58	0.56 (0.13, 0.99)		*0.01*

* Beta coefficient represents the estimated difference in the age- and sex-standardised combined muscular strength score per one-unit increase in a continuous variable from its mean or for each level of a categorical variable.
Abbreviations: BMI, body mass index; CI, confidence interval; PWC_{170}, physical work capacity at a heart rate of 170 beats per minute; SES, socioeconomic status; VO_2 max, maximal oxygen consumption.

Table 3. Associations between modifiable and environmental factors and muscular power for males and females, adjusted for age.

	Males				Females			
Characteristic	n	Beta coefficient (95% CI)*	r-squared	*p-value*	n	Beta coefficient (95% CI)*	r-squared	*p-value*
Adiposity and fat-free mass								
BMI, kg/m^2	4292	–0.05 (–0.06, –0.03)	0.03	*<0.001*	4163	–0.04 (–0.06, –0.03)	0.02	*<0.001*
BMI categories								
Normal	3810	REF	0.03	REF	3655	REF	0.02	REF
Overweight	410	–0.44 (–0.54, –0.34)		*<0.001*	443	–0.34 (–0.44, –0.25)		*<0.001*
Obese	72	–0.78 (–1.01, –0.55)		*<0.001*	65	–0.58 (–0.82, –0.34)		*<0.001*
Waist circumference, per 10 cm	4294	–0.18 (–0.22, –0.13)	0.03	*<0.001*	4160	–0.24 (–0.30, –0.18)	0.02	*<0.001*
Sum of skinfolds, per 10 mm	1399	–0.18 (–0.22, –0.15)	0.08	*<0.001*	1370	–0.14 (–0.17, –0.11)	0.07	*<0.001*
Fat-free mass, per 1 kg	1399	0.04 (0.03, 0.05)	0.03	*<0.001*	1370	0.01 (–0.00, 0.03)	0.04	*0.14*
Cardiorespiratory fitness								
1.6 km run, per 1 min	4038	–0.24 (–0.26, –0.22)	0.13	*<0.001*	3827	–0.25 (–0.27, –0.22)	0.12	*<0.001*
PWC_{170}, per 10 watts	1331	0.04 (0.02, 0.07)	0.01	*<0.001*	1284	0.09 (0.06, 0.12)	0.03	*<0.001*
Estimated VO_2 max, per 1 ml/kg/min	4035	0.08 (0.07, 0.10)	0.10	*<0.001*	3826	0.07 (0.06, 0.07)	0.07	*<0.001*
Flexibility and speed capability								
Sit and reach, per cm	4283	0.04 (0.03, 0.05)	0.05	*<0.001*	4151	0.04 (0.03, 0.04)	0.05	*<0.001*
50m run, per second	4103	–0.62 (–0.67, –0.57)	0.28	*<0.001*	3952	–0.63 (–0.66, –0.60)	0.25	*<0.001*
Physical activity								
School physical activity, per 60 mins/week	2882	0.03 (0.01, 0.05)	0.00	*0.001*	2758	0.06 (0.04, 0.09)	0.01	*<0.001*
Non–school physical activity, per 60 mins/week	2930	0.01 (0.00, 0.02)	0.00	*0.008*	2734	0.01 (0.00, 0.02)	0.00	*0.002*

Total weekly physical activity, per 60 mins/week	3245	0.02 (0.01, 0.02)	0.01	*<0.001*	3135	0.03 (0.02, 0.03)	0.01	*<0.001*
Parental exercise								
Both parents are inactive	1299	REF	0.00	*REF*	1187	REF	0.01	REF
Father active only	626	0.03 (–0.06, 0.13)		*0.49*	563	0.10 (–0.00, 0.20)		*0.06*
Mother active only	518	0.01 (–0.10, 0.11)		*0.92*	531	0.09 (–0.01, 0.19)		*0.08*
Both parents are active	550	0.05 (–0.05, 0.15)		*0.33*	626	0.24 (0.14, 0.33)		*<0.001*
Dietary quality and intake								
Dietary Guidelines Index, per 10 units	2528	0.06 (0.03, 0.09)	0.01	*<0.001*	2490	0.06 (0.03, 0.09)	0.01	*<0.001*
Fruit intake								
1 serve or less	1561	REF	0.01	*REF*	1507	REF	0.00	REF
2–3 serves	598	0.14 (0.05, 0.24)		*0.003*	654	0.10 (0.01, 0.19)		*0.03*
4 or more serves	369	0.25 (0.14, 0.36)		*<0.001*	329	0.13 (0.01, 0.25)		*0.04*
Vegetable intake								
1 serve or less	1145	REF	0.00	*REF*	1206	REF	0.00	REF
2–3 serves	732	–0.02 (–0.11, 0.07)		*0.66*	813	0.07 (–0.02, 0.16)		*0.12*
4 or more serves	651	0.13 (0.03, 0.22)		*0.01*	471	–0.01 (–0.12, 0.09)		*0.82*
Protein, total daily intake per 10 grams	2528	0.07 (0.05, 0.08)	0.03	*<0.001*	2490	0.03 (0.02, 0.05)	0.01	*<0.001*
Protein intake								
2 serves or less	945	REF	0.01	*REF*	1311	REF	0.01	REF
3–4 serves	934	0.07 (–0.02, 0.16)		*0.12*	861	0.05 (–0.03, 0.14)		*0.22*
5 or more serves	649	0.30 (0.20, 0.40)		*<0.001*	318	0.24 (0.12, 0.36)		*<0.001*
Socioeconomic position								
Area–level SES								
Low	309	REF	0.00	*REF*	269	REF	0.01	REF
Medium–low	1228	0.10 (–0.02, 0.23)		*0.10*	1185	0.21 (0.08, 0.34)		*0.002*

Medium–high	910	0.18 (0.06, 0.31)		*0.005*	881	0.24 (0.10, 0.37)		*0.001*
High	740	0.19 (0.06, 0.33)		*0.004*	745	0.30 (0.16, 0.44)		*<0.001*
School type								
State	3225	REF	0.00	*REF*	3119	REF	0.00	REF
Catholic	824	0.11 (0.03, 0.18)		*0.007*	844	–0.01 (–0.09, 0.06)		*0.77*
Independent	246	0.21 (0.08, 0.34)		*0.001*	201	0.28 (0.14, 0.42)		*<0.001*

* Beta coefficient represents the estimated difference in the age- and sex-standardised measure of muscular power per one-unit increase in a continuous variable from its mean or for each level of a categorical variable.

Abbreviations: BMI, body mass index; CI, confidence interval; PWC_{170}, physical work capacity at a heart rate of 170 beats per minute; SES, socioeconomic status; VO_2 max, maximal oxygen consumption.

Online-only supplement

Table S1. Associations between modifiable and environmental factors and the combined muscular strength score for males and females separately, adjusted for age and all other listed variables.

	Males (n=746)†		Females (n=688)‡	
Characteristic	Beta coefficient (95% CI)*	*p-value*	Beta coefficient (95% CI)*	*p-value*
Adiposity and fat-free mass				
Sum of skinfolds, per 10 mm	–0.32 (–0.40, –0.25)	*<0.001*	–0.18 (–0.25, –0.11)	*<0.001*
Fat-free mass, per 1 kg	0.09 (0.07, 0.12)	*<0.001*	0.06 (0.03, 0.08)	*<0.001*
Cardiorespiratory fitness				
1.6 km run, per 1 min	n/r	n/r	–0.16 (–0.25, –0.06)	*0.001*
Estimated VO_2 max, per 1 ml/kg/min	–0.00 (–0.04, 0.03)	*0.78*	n/r	n/r
Flexibility and speed capability				
Sit and reach, cm	0.03 (0.02, 0.04)	*<0.001*	0.04 (0.02, 0.05)	*<0.001*
50m run, per second	–0.80 (–0.97, –0.63)	*<0.001*	–0.94 (–1.15, –0.73)	*<0.001*
Physical activity				
Total weekly physical activity, per 60 mins/week	0.01 (–0.00, 0.02)	*0.20*	–0.00 (–0.01, 0.02)	*0.90*
Parental exercise				
Both parents are inactive	n/r	n/r	REF	REF
Father active only	n/r	n/r	0.08 (–0.19, 0.36)	0.55
Mother active only	n/r	n/r	0.12 (–0.17, 0.41)	0.41
Both parents are active	n/r	n/r	0.10 (–0.19, 0.38)	0.50
Dietary quality and intake				
Fruit intake				
1 serve or less	REF	REF	n/r	n/r
2–3 serves	0.00 (–0.22, 0.22)	*0.99*	n/r	n/r
4 or more serves	0.21 (–0.07, 0.48)	*0.14*	n/r	n/r
Vegetable intake				
1 serve or less	REF	REF	n/r	n/r
2–3 serves	0.01 (–0.21, 0.23)	*0.91*	n/r	n/r

4 or more serves	0.16 (–0.07, 0.39)	*0.17*	n/r	n/r
Protein intake				
2 serves or less	n/r	n/r	REF	*REF*
3–4 serves	n/r	n/r	0.13 (–0.09, 0.35)	*0.25*
5 or more serves	n/r	n/r	–0.30 (–0.60, 0.00)	*0.05*
Protein, total daily intake per 10 grams	–0.01 (–0.04, 0.02)	*0.40*	n/r	n/r
Socioeconomic position				
Area-level SES				
Low	REF	REF	REF	REF
Medium–low	–0.20 (–0.53, 0.14)	*0.26*	0.01 (–0.38, 0.40)	*0.96*
Medium–high	–0.29 (–0.64, 0.06)	*0.10*	–0.05 (–0.46, 0.35)	*0.80*
High	–0.15 (–0.51, 0.21)	*0.41*	–0.09 (–0.50, 0.32)	*0.67*
School type				
State	REF	REF	REF	REF
Catholic	–0.28 (–0.52, –0.05)	*0.02*	–0.14 (–0.39, 0.10)	*0.26*
Independent	0.47 (0.09, 0.84)	*0.02*	–0.05 (–0.59, 0.48)	*0.84*

* Beta coefficient represents the estimated difference in the age and sex standardised combined muscular strength score per one-unit increase in a continuous variable from its mean or for each level of a categorical variable.
† r-squared for male multivariable model=0.41
‡ r-squared for female multivariable model=0.32
Abbreviations: CI, confidence interval; n/r, not retained in multivariable model; SES, socioeconomic status.

Table S2. Associations between modifiable and environmental factors and muscular power for males and females separately, adjusted for age and all other listed variables.

	Males (n=761)†		Females (n=710)‡	
Characteristic	Beta coefficient (95% CI)*	*p-value*	Beta coefficient (95% CI)*	*p-value*
Adiposity and fat-free mass				
Sum of skinfolds, per 10 mm	–0.15 (–0.19, –0.10)	*<0.001*	–0.04 (–0.08, –0.00)	*0.03*
Fat-free mass, per 1 kg	0.03 (0.02, 0.04)	*<0.001*	n/r	n/r
Cardiorespiratory fitness				
1.6 km run, per 1 min	0.02 (–0.03, 0.07)	*0.47*	–0.06 (–0.11, –0.02)	*0.006*
Flexibility and speed capability				
Sit and reach, cm	0.03 (0.02, 0.04)	*<0.001*	0.02 (0.02, 0.03)	*<0.001*
50m run, per second	–0.60 (–0.71, –0.49)	*<0.001*	–0.58 (–0.68, –0.48)	*<0.001*
Physical activity				
Total weekly physical activity, per 60 mins/week	0.01 (–0.00, 0.02)	*0.06*	0.00 (–0.01, 0.01)	*0.64*
Parental exercise				
Both parents are inactive	n/r	n/r	REF	REF
Father active only	n/r	n/r	–0.00 (–0.17, 0.16)	0.96
Mother active only	n/r	n/r	–0.02 (–0.19, 0.16)	0.85
Both parents are active	n/r	n/r	0.08 (–0.09, 0.25)	0.33
Dietary quality and intake				
Dietary guideline index, per 10 units	0.02 (–0.03, 0.08)	0.41	0.02 (–0.04, 0.08)	0.49
Fruit intake				
1 serve or less	REF	REF	REF	REF
2–3 serves	0.08 (–0.06, 0.22)	*0.25*	0.12 (–0.04, 0.27)	*0.13*
4 or more serves	0.05 (–0.12, 0.23)	*0.57*	0.17 (–0.02, 0.35)	*0.08*
Vegetable intake				
1 serve or less	REF	REF	n/r	n/r
2–3 serves	–0.06 (–0.20, 0.08)	*0.41*	n/r	n/r
4 or more serves	0.01 (–0.15, 0.16)	*0.94*	n/r	n/r
Protein, total daily intake per 10 grams	0.02	*0.09*	0.01 (–0.01, 0.04)	0.40

Socioeconomic position				
Area-level SES				
Low	REF	REF	REF	REF
Medium–low	0.08 (–0.12, 0.34)	*0.33*	0.42 (0.18, 0.65)	*0.001*
Medium–high	0.23 (0.02, 0.44)	*0.03*	0.40 (0.15, 0.64)	*0.001*
High	0.33 (0.12, 0.55)	*0.003*	0.45 (0.20, 0.70)	*<0.001*
School type				
State	REF	REF	REF	REF
Catholic	0.27 (0.13, 0.42)	*<0.001*	–0.07 (–0.22, 0.08)	*0.40*
Independent	0.31 (0.08, 0.53)	*0.008*	0.33 (0.00, 0.66)	*0.05*

* Beta coefficient represents the estimated difference in the age- and sex-standardised measure of muscular power per one-unit increase in a continuous variable from its mean or for each level of a categorical variable.

† r-squared for male multivariable model=0.42

‡ r-squared for female multivariable model=0.36

Abbreviations: CI, confidence interval; n/r, not retained in multivariable model; SES, socioeconomic status.