Associations of muscular and cardiorespiratory fitness with total and central body fat in adolescents: The HELENA Study

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ABSTRACT

Objective To examine the association of health-related physical fitness with total and central body fat in adolescents.

Participants/Methods The present cross-sectional study comprises 363 Spanish adolescents (186 female participants) aged 12.5–17.5 years. We assessed fitness by the 20-m shuttle run test (cardiorespiratory fitness); the handgrip strength, the standing broad jump and the Abalakov tests (muscular strength); and the 4×10-m shuttle run test (speed–agility). Total body fat was measured by dual energy x-ray absorptiometry (DXA), BodPod and sum of six skinfolds, and central body fat was measured by DXA at three regions (R1, R2 and R3) and waist circumference.

Results The Abalakov, the standing broad jump, the 4×10-m shuttle run and the 20-m shuttle run tests were negatively associated with all markers of total and central body fat in men and women after controlling for age, pubertal status and objectively assessed physical activity ($p<0.01$). Handgrip strength test was positively associated with waist circumference ($p<0.01$).

Conclusions Lower body muscular strength and cardiorespiratory fitness are negatively and consistently associated with total and central body fat in adolescents, whereas levels of upper body muscular strength were superior in adolescents with higher levels of central body fat.

INTRODUCTION

Health-related physical fitness (hereinafter called fitness) refers to those components of fitness that have a relationship with the ability to perform daily activities with vigour and by traits and capacities that are associated with a lower risk for the development of chronic diseases and premature death: cardiorespiratory fitness, musculoskeletal fitness (eg, muscular strength), motor fitness (ie, speed–agility) and body composition.[1–3]

Fitness is considered an important marker of health already in youth.[3 4] There is growing evidence that fitness at childhood and adolescence is negatively associated with total and central body fat later in life;[5 6] and similar findings were observed in cross-sectional studies.[7–10] Studies analysing the association between fitness and body composition measured with sophisticated methods such as dual energy x-ray absorptiometry (DXA), CT or magnetic resonance are scarce and mainly confined to cardiorespiratory fitness.[11–15] Therefore, additional studies are needed to better understand the association between fitness and fatness. This will provide useful insights for intervention studies focused on enhancing fitness and reducing fatness.

The purpose of the present study was to determine the association of fitness (ie, cardiorespiratory fitness, muscular strength and speed/agility) with total and central body fat measured by DXA, BodPod and anthropometry in a sample of Spanish adolescents participating in the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectionals study).

RESEARCH METHODS AND PROCEDURES

Subjects

The HELENA-CSS is a multi-centre, cross-sectional study performed in 10 European cities that was designed to obtain reliable and comparable data on nutritional status, cardiovascular profile, physical activity (PA) and fitness of a sample of European adolescents.[16 17] The average number of adolescents to be measured in each city (Athens in Greece, Dortmund in Germany, Ghent in Belgium, Heraklion in Greece, Lille in France, Pecs in Hungary, Rome in Italy, Stockholm in Sweden, Vienna in Austria and Zaragoza in Spain) was estimated as 300. All participants were recruited at schools and met the general HELENA-CSS inclusion criteria (age range 12.5–17.5 years, not participating simultaneously in another clinical trial and free of any acute infection lasting <1 week before the inclusion).[16 17] The present study comprises 363 adolescents (186 female and 177 male participants) from Zaragoza (Spain) aged 12.5–17.5 years with at least valid DXA data. After receiving complete information about the aims and methods of the study, all adolescents and their parents or guardians signed the informed written consent.

The study was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Edinburgh 2000). For the Spanish sample, the study protocol was approved by the Research Ethics Committee of the Government of Aragón (CEICA; Spain). Complete description of ethical issues and good clinical practice within the HELENA-CSS can be found elsewhere.[18]

Health-related physical fitness

Fitness was assessed as previously reported by Ortega *et al*.[19] In brief, cardiorespiratory fitness was assessed by the 20-m shuttle run test.[19 20] Upper body muscular strength was measured with the handgrip strength test[21] and lower body muscular strength with the standing broad jump and the Abalakov tests.[19] The Abalakov test assesses the lower limb explosive strength. In a standing position, the adolescent performs a vertical jump with a prior fast counter movement. The adolescent is allowed to freely coordinate the arms and trunk movements in order to reach the maximum height. Speed of movement and agility were assessed with the 4×10-m shuttle run test.[19] The scientific rationale for the selection of all these tests has been previously published.[22] The physical fitness tests mentioned above have shown to be reliable and valid in adolescent population.[19 23] We performed a reliability study where we assessed the above mentioned fitness tests in 123 adolescents 2 weeks apart, and we did not observed a learning or a fatigue effect for any of the tests.[19] Findings from a systematic review that comprehensively studied the validity (ie, the extent to which a field test correlates with the gold standard) of the existing field-based fitness tests used in children and adolescents indicated that there is strong evidence that these are valid.[23]

Body fat assessment

We assessed body fat by DXA, BodPod and anthropometry.

Body fat assessed by DXA

Body fat was assessed using a paediatric version of the software QDR Explorer (software version 12.4; Hologic Corp., Waltham, Massachusetts, USA). The DXA was calibrated using a lumbar spine phantom as recommended by the manufacturer, and adolescents were scanned in supine position. Analysis of total body fat mass was performed using the extended research mode according to the operating manual. Percentage total body fat was calculated as total body fat mass divided by body weight and multiplied by 100.

Abdominal adiposity was assessed at three different regions, R1, R2 and R3.[24 25] A rectangle was drawn on the digital scan image to establish every region. All of them have the lower horizontal border on the top of iliac crest. For R1, the upper border was established parallel with the end of the lowest rib. The upper border of the R2 was parallel with the junction of the T12 and L1 vertebrae and for the R3 was parallel to the middle of the costo-vertebrae articulation of the last rib. The lateral sides of these regions were adjusted to include all the body tissue.

Body fat assessed by BodPod

Body volume was measured by BodPod using standardised procedures.[26] The BodPod was calibrated prior every analysis according to the manufacturer's guidelines. Subjects wore clothing according to the manufacturer's recommendation (a swimsuit and a swim cap) to rule out air trapped in clothes and hair. Adolescents were weighed on the BodPod calibrated digital scale and then entered the BodPod chamber. Body volume was measured twice by the machine to ensure measurement reliability. If the first two readings for body volume differed by more than 150 ml, a third measurement was taken. If additional readings were needed, the BodPod was recalibrated, and the measurements were repeated for that subject. Percentage total body fat was calculated using the equations reported by Siri.[27] Thoracic gas volume was measured following the manufacturer's recommendations.[26] This value was integrated into the calculation of body volume. Total body fat mass (kilograms) was calculated as percentage total body fat mass multiplied by body mass (kilograms) and then divided by 100.

Anthropometry

The anthropometric methods followed in the HELENA-CSS has been described in detail by Nagy *et al*.[28] Body mass index was calculated as body mass (kilograms) divided by height (meters) squared.

Skinfold thickness was measured to the nearest 0.2 mm in triplicate in the left side at biceps, triceps, subscapular, suprailiac, thigh and medial calf with a Holtain Caliper (Crymmych, UK).[28] The sum of six skinfold thickness was used as an indicator of total body fat. Waist circumference was measured to the nearest 1 mm in triplicate at the level of the natural waist, which is the narrowest part of the torso, as seen from the anterior aspect with an anthropometric un-elastic tape SECA 200 and was used as a surrogate measurement of central body fat. It was recorded to the nearest 0.1 cm.

Pubertal status

Pubertal status was evaluated by experienced physicians by direct observation according to the criteria of Tanner and Whitehouse[29] and as described elewhere.[30]

Physical activity

A uni-axial accelerometer (Actigraph MTI, model GT1M; Manufacturing Technology Inc., Fort Walton Beach, Florida, USA) was used to assess PA. Adolescents were instructed to place the monitor underneath the clothing, at the lower back, using an elastic waist band and wear it for seven consecutive days. They were also instructed to wear the accelerometer during all time awake and only to remove it during water-based activities. At least 3 days of recording with a minimum of 8 h registration per day was set as an inclusion criterion. In this study, the time sampling interval was set at 15 s (epoch). A measure of total volume of activity (hereafter called average PA) was expressed as the sum of recorded counts per epoch divided by total daily registered time (counts/min).

Statistical analysis

The data are presented as means±SD unless otherwise stated. To achieve normality in the residuals, markers of total and central body fat, handgrip strength test, Abalakov test and 20-m shuttle run test values were transformed to the natural logarithm. Gender differences were assessed by one-way analysis of variance.

Multiple regression was used to study the association of fitness (ie, handgrip strength, standing broad jump, Abalakov, 4×10- and 20-m shuttle run tests) with markers of total (ie, DXA, BodPod and sum of six skinfolds) and central body fat (ie, R1, R2 and R3 by DXA, and waist circumference). All these relationships were analysed in separate regression models and using age, pubertal status and PA as covariates (ie, set of confounders). Since we observed a significant interaction effect between sex and most fitness components, all analyses were performed separately for male and female participants.

R^2 change was used as the measure of the relationship between PA and the part of the outcome (total and central body fat) that is not explained by the other predictors in the model (age, pubertal status and PA). We used Bonferroni and Holm method to correct for multiple testing.[31]

The analyses were performed using the Statistical Package for Social Sciences (SPSS, vs 16.0 for WINDOWS; SPSS Inc., Chicago, Illinois, USA), and the level of significance was set to <0.05.

RESULTS

In female participants (N=186), there were 2 (1.1%) missing data for the standing broad jump test, 1 (0.5%) for the Abalakov test, 9 (4.8%) for the 4×10-m shuttle run test, 45 (24.2%) for the 20-m shuttle run test, 8 (4.3%) for the skinfold thickness and 14 (7.5%) for the BodPod. In male participants (n=177), there were 1 (0.6%) missing data for the Abalakov test, 11 (6.2%) for the 4×10-m shuttle run test, 43 (24.3%) for the 20-m shuttle run test, 5 (2.8%) for the skinfold thickness, 1 (0.6%) for the waist circumference and 4 (2.3%) for the BodPod. PA data were missing in 14 female (7.5%) and 8 male (4.5%) participants.

The characteristics of the study population by gender are shown in table 1. Female participants showed higher levels of total body fat and abdominal adiposity by DXA than male participants (all p<0.001). Female participants had lower values in all fitness tests (p<0.001), and they were less physically active than male participants (p<0.001).

The association between fitness and markers of total body fat are shown in tables 2 and 3 for female and male participants, respectively. All the markers of total body fat studied were negatively associated with standing broad jump (p<0.001), Abalakov (p<0.001), 4×10-m shuttle run test (p<0.01) and 20-m shuttle run test (p<0.001). Moreover, total body fat measured by DXA was positively associated with handgrip strength in female participants (p=0.028); yet, this association disappeared when we corrected for multiple comparisons.

The association between fitness and markers of central body fat are shown in tables 4 and 5 for female and male participants, respectively. All the studied markers of central body fat were negatively associated with the standing broad jump, Abalakov and the 20-m shuttle run tests in male and female participants. Moreover, waist circumference was positively associated with handgrip strength (p<0.01) and 4×10-m shuttle run test (p<0.05) in male and female participants. The results did not change after further controlling for height. Restriction of the analysis to a subset of individuals with complete data on all covariates did not materially change the results.

DISCUSSION

The present study shows that cardiorespiratory fitness and lower body muscular strength are negatively associated with markers of total and central body fat in young people after controlling for age, pubertal status and PA. As in any cross-sectional study, we cannot state the direction of the associations; indeed, there might be a reciprocal association between fitness and fatness. The excess of body fat is an extra load that could adversely affect fitness performance, especially when

Table 1 Characteristics of the study participants by gender

	All (n=363)	Female participants (n=186)	Male participants (n=177)
Age (years)	14.8±1.2	14.8±1.1	14.8±1.3
Tanner stage (%)			
Stage 1	0.0	0.0	0.0
Stage 2	2.6	3.0	2.3
Stage 3	7.2	2.0	5.2
Stage 4	11.7	2.9	8.9
Stage 5	78.5	46.1	32.4
Height (m)	1.7±0.1	1.6±0.1*	1.7±0.1
Weight (kg)	58.0±11.3	54.8±9.2*	61.3±12.4
BMI (kg/m^2)	21.3±3.3	21.1±3.3	21.4±3.3
Handgrip strength (kg)	27.9±7.9	23.4±4.1*	32.6±8.1
Standing broad jump (cm)	156.1±33.7	136.6±22.4*	176.5±31.5
Abalakov (cm)	28.0±7.8	23.8±5.0*	32.3±7.8
4×10-m Shuttle run test (s)	11.8±1.0	12.3±0.8*	11.2±0.9
20-m Shuttle run test (stages)	6.0±2.7	4.4±1.8*	7.7±2.5
Sum of six skinfolds (mm)	94.0±38.6	106.9±32.4*	80.7±40.1
Waist circumference (cm)	73.6±8.6	71.9±7.7*	75.5±9.1
Fat mass by DXA (kg)	15.0±6.0	16.4±5.3*	13.4±6.2
Fat mass by DXA (%)	25.9±7.6	30.0±5.3*	21.6±7.2
Abdominal adiposity R1 by DXA (kg)	0.9±0.6	1.0±0.6*	0.8±0.5
Abdominal adiposity R2 by DXA (kg)	1.2±0.8	1.3±0.8*	1.1±0.7
Abdominal adiposity R3 by DXA (kg)	1.4±0.9	1.5±0.9*	1.3±0.9
Fat mass by BodPod (kg)	14.2±6.8	15.7±6.0*	12.6±7.2
Fat mass by BodPod (%)	24.1±8.8	27.9±6.6*	19.9±9.0
Average physical activity (cpm)	418.3±145.6	369.7±118.8*	467.8±153.8

Abdominal adiposity R1 includes a body area from top of the iliac crest to the end of the lowest rib; R2 includes from top of the iliac crest to the junction of the T12 and L1 vertebrae; R3 includes from top of the iliac crest to the middle of the costo-vertebrae articulation of the last rib.
*p≤0.001.
BMI, body mass index; cpm, counts per min; DXA, dual energy x-ray absorptiometry.

Table 2 Regression analysis between health-related physical fitness components and markers of total body fat in female adolescents, after controlling for age, pubertal status and physical activity

	Female adolescents						
Dependent variable	**Predictors**	**n**	**β**	**p**	**sr**	**R^2**	**R^2 change**
Total body fat by DXA	Handgrip strength	165	0.174	0.028	0.160	0.144	0.026
	Standing broad jump	163	−0.300	<0.001	−0.289	0.208	0.084
	Abalakov	164	−0.448	<0.001	−0.443	0.316	0.196
	4×10-m Shuttle run test*	157	0.215	0.004	0.212	0.173	0.045
	20-m Shuttle run test	127	−0.462	<0.001	−0.436	0.331	0.190
Total body fat by BodPod	Handgrip strength	164	0.128	0.119	0.117	0.090	0.014
	Standing broad jump	163	−0.356	<0.001	−0.344	0.194	0.118
	Abalakov	163	−0.460	<0.001	−0.455	0.286	0.207
	4×10-m Shuttle run test*	157	0.260	<0.001	0.252	0.143	0.066
	20-m Shuttle run test	127	−0.425	<0.001	−0.402	0.253	0.162
Sum of six skinfolds	Handgrip strength	158	0.125	0.138	0.115	0.059	0.013
	Standing broad jump	156	−0.246	0.002	−0.239	0.105	0.057
	Abalakov	157	−0.415	<0.001	−0.411	0.216	0.169
	4×10-m Shuttle run test*	150	0.221	0.006	0.219	0.100	0.048
	20-m Shuttle run test	120	−0.408	<0.001	−0.388	0.199	0.150

All variables were log transformed, except standing broad jump and 4×10-m shuttle run tests.
*In the 4×10-m shuttle run test, the greater the score (sec) the worse the performance. Consequently, positive coefficients mean a negative association between the test performance and adiposity.
β, multiple regression coefficients; sr, semipartial correlations; R^2 and R^2 change, coefficients of determination.

Table 3 Regression analysis between health-related physical fitness components and markers of total body fat in male adolescents, after controlling for age, pubertal status and physical activity

	Male adolescents						
Dependent variable	**Predictors**	**n**	**β**	**p**	**sr**	**R^2**	**R^2 change**
Total body fat by DXA	Handgrip strength	162	0.193	0.086	0.133	0.048	0.018
	Standing broad jump	162	−0.520	<0.001	−0.416	0.208	0.173
	Abalakov	161	−0.585	<0.001	−0.482	0.267	0.232
	4×10-m Shuttle run test*	154	0.475	<0.001	0.415	0.207	0.172
	20-m Shuttle run test	121	−0.535	<0.001	−0.494	0.266	0.244
Total body fat by BodPod	Handgrip strength	158	0.116	0.323	0.078	0.039	0.006
	Standing broad jump	158	−0.605	<0.001	−0.478	0.268	0.228
	Abalakov	157	−0.641	<0.001	−0.522	0.311	0.273
	4×10-m Shuttle run test*	150	0.513	<0.001	0.443	0.233	0.196
	20-m Shuttle run test	118	−0.546	<0.001	−0.503	0.284	0.253
Sum of six skinfolds	Handgrip strength	157	0.048	0.669	0.033	0.089	0.001
	Standing broad jump	157	−0.561	<0.001	−0.447	0.293	0.200
	Abalakov	156	−0.607	<0.001	−0.501	0.340	0.251
	4×10-m Shuttle run test*	149	0.491	<0.001	0.430	0.288	0.185
	20-m Shuttle run test	119	−0.544	<0.001	−0.503	0.344	0.253

All variables were log transformed, except standing broad jump and 4×10-m shuttle run tests.
*In the 4×10-m shuttle run test, the greater the score (seconds), the worse the performance. Consequently, positive coefficients mean a negative association between the test performance and adiposity.
β, multiple regression coefficients; sr, semipartial correlations; R^2 and R^2 change, coefficients of determination.

measured with weight-bearing tests. However, it is also possible that fit adolescents possess higher levels of lean body mass compared to their unfit counterparts. Under most circumstances, and especially when physically inactive, resting energy expenditure is the largest component of total energy expenditure. The energy expenditure related to muscle metabolism (lean body mass) is the only component of resting energy expenditure that might vary considerably. Over a long period, the maintenance of a large muscle mass and consequent muscle protein turnover can contribute to the prevention of obesity. This may partially explain why fit adolescents have less fat mass than those who are unfit.

Similarly to other studies, the association between fitness and body fat markers was weaker in female than in male participants,[13] yet remained after controlling for PA assessed by accelerometers. The most consistent associations were observed for the Abalakov and the 20-m shuttle run tests in male and female participants. The results were fairly consistent regardless of the methodology used to assess body fat mass; yet, the associations were stronger when markers of body fat were measured by DXA. In male participants, Abalakov and 20-m shuttle run tests explained ~25% of the variance of total body fat. High body fat may have a stronger adverse effect on actions that require a displacement of the body in a vertical axis, compared to a horizontal axis.

We also observed an inverse association between muscular strength assessed with weight-bearing tests and total and central body fat, which agree with other studies.[9–11 32]

Table 4 Regression analysis between health-related physical fitness components and markers of central body fat in female adolescents, after controlling for age, pubertal status and physical activity

	Female adolescents						
Dependent variable	**Predictors**	**n**	**β**	**p**	**sr**	**R^2**	**R^2 change**
Abdominal adiposity R1 by DXA	Handgrip strength	165	0.120	0.143	0.111	0.074	0.012
	Standing broad jump	163	−0.309	<0.001	−0.298	0.154	0.089
	Abalakov	164	−0.450	<0.001	−0.445	0.261	0.198
	4×10-m Shuttle run test*	157	0.278	<0.001	0.275	0.142	0.076
	20-m Shuttle run test	127	−0.481	<0.001	−0.455	0.296	0.207
Abdominal adiposity R2 by DXA	Handgrip strength	165	0.107	0.191	0.099	0.073	0.010
	Standing broad jump	163	−0.326	<0.001	−0.315	0.165	0.099
	Abalakov	164	−0.458	<0.001	−0.453	0.270	0.205
	4×10-m Shuttle run test*	157	0.275	<0.001	0.272	0.141	0.074
	20-m Shuttle run test	127	−0.478	<0.001	−0.452	0.292	0.204
Abdominal adiposity R3 by DXA	Handgrip strength	165	0.101	0.221	0.093	0.065	0.009
	Standing broad jump	163	−0.317	<0.001	−0.306	0.153	0.094
	Abalakov	164	−0.466	<0.001	−0.461	0.270	0.212
	4×10-m Shuttle run test*	157	0.268	0.001	0.265	0.131	0.070
	20-m Shuttle run test	127	−0.463	<0.001	−0.438	0.271	0.192
Waist circumference	Handgrip strength	165	0.230	0.004	0.211	0.122	0.045
	Standing broad jump	163	−0.149	0.055	−0.144	0.100	0.021
	Abalakov	164	−0.376	<0.001	−0.372	0.216	0.139
	4×10-m Shuttle run test*	157	0.168	0.030	0.166	0.108	0.027
	20-m Shuttle run test	127	0.120	0.143	0.111	0.074	0.012

All variables were log transformed, except standing broad jump and 4×10-m shuttle run tests.
*In the 4×10-m shuttle run test, the greater the score (seconds), the worse the performance.
Consequently, positive coefficients mean a negative association between the test performance and adiposity.
β, multiple regression coefficients; sr, semipartial correlations; R^2 and R^2 change, coefficients of determination.

Table 5 Regression analysis between health-related physical fitness components and markers of central body fat in male adolescents, after controlling for age, pubertal status and physical activity

	Male adolescents						
Dependent variable	**Predictors**	**n**	**β**	**p**	**sr**	**R^2**	**R^2 change**
Abdominal adiposity R1 by DXA	Handgrip strength	162	0.156	0.171	0.107	0.020	0.012
	Standing broad jump	162	−0.514	<0.001	−0.411	0.182	0.169
	Abalakov	161	−0.592	<0.001	−0.488	0.251	0.238
	4×10-m Shuttle run test*	154	0.478	<0.001	0.418	0.187	0.174
	20-m Shuttle run test	121	−0.563	<0.001	−0.521	0.277	0.271
Abdominal adiposity R2 by DXA	Handgrip strength	162	0.213	0.060	0.147	0.028	0.022
	Standing broad jump	162	−0.492	<0.001	−0.393	0.165	0.154
	Abalakov	161	−0.586	<0.001	−0.483	0.245	0.233
	4×10-m Shuttle run test*	154	0.452	<0.001	0.394	0.165	0.155
	20-m Shuttle run test	121	−0.548	<0.001	−0.506	0.258	0.256
Abdominal adiposity R3 by DXA	Handgrip strength	162	0.184	0.107	0.127	0.010	0.016
	Standing broad jump	162	−0.499	<0.001	−0.399	0.157	0.159
	Abalakov	161	−0.586	<0.001	−0.483	0.232	0.234
	4×10-m Shuttle run test*	154	0.449	<0.001	0.392	0.150	0.154
	20-m Shuttle run test	121	−0.538	<0.001	−0.497	0.245	0.247
Waist circumference	Handgrip strength	161	0.476	<0.001	0.328	0.127	0.108
	Standing broad jump	161	−0.421	<0.001	−0.377	0.133	0.114
	Abalakov	160	−0.491	<0.001	−0.406	0.186	0.165
	4×10-m Shuttle run test*	153	0.411	<0.001	0.359	0.149	0.129
	20-m Shuttle run test	120	−0.532	<0.001	−0.490	0.283	0.240

All variables were log transformed, except standing broad jump and 4×10-m shuttle run tests.
*In the 4×10-m shuttle run test, the greater the score (seconds), the worse the performance.
Consequently, positive coefficients mean a negative association between the test performance and adiposity.
β, multiple regression coefficients; sr, semipartial correlations; R^2 and R^2 change, coefficients of determination.

Malina *et al*[10] examined the association between five motor performance items and the sum of five skinfolds in a representative sample of Belgium girls and reported a negative association of balance, speed, power and strength with adiposity. Deforche *et al*[32] examined Flemish youth from the "Eurofit-Barometer 1997" and observed that obese youth had poorer performances in all tests requiring propulsion or lifting of the body mass compared with their non-obese counterparts.

Okely *et al*[9] analysed students of primary and high school as part of the "1997 New South Wales Schools Fitness and Physical Activity Survey" and concluded that overweight students were less likely to have high levels of fitness, especially for locomotor skills than object-control skills.

It is also important to emphasise the positive association observed between handgrip strength and central body fat.[10 32–34] It has been suggested that the excess of adiposity yields to increases in fat-free mass in order to support this extra load.[35] This may explain that individuals with an excess of adiposity performed better in non-weight-dependent tests such as handgrip tests. This is in agreement with findings from the Alimentación y Valoración del Estado Nutricional en Adolescentes study in Spanish adolescents, where we observed higher handgrip strength in overweight and obese adolescents compared to their underweight or normal-weight peers.[36]

Muscular strength training is prescribed by the major health organisations due to its important role in the performance of exercise and activities of daily living as well as in preventing disease.[37–40] Findings from longitudinal studies indicate that changes in muscular strength from childhood to adolescence seems to be negatively associated with changes in overall adiposity, whereas the association between changes in muscular strength and changes in central adiposity are less evident.[3]

The observed negative association between cardiorespiratory fitness and body fat mass concur with previous studies where sophisticated techniques to assess body composition were used.[12–15 41 42] Gutin *et al*[13] assessed body fat by DXA in youth and showed a negative association with cardiorespiratory fitness. Arsenault *et al*[43] analysed young to middle-aged men from Québec Family Study and reported that visceral adiposity assessed by CT and total body fat assessed by underwater weighing was negatively associated with cardiorespiratory fitness. Similarly, Winsley *et al*[12] showed that visceral adipose tissue assessed by magnetic resonance was inversely associated with cardiorespiratory fitness in children. Ara *et al*[11] studied pre-pubertal children and showed that fat mass explained 27% of the performance in cardiorespiratory fitness. These findings were also consistent when anthropometric methods are used. Ortega *et al* observed that cardiorespiratory fitness was inversely associated with waist circumference in Spanish[8] and Swedish youth.[44]

Although we controlled for several potential confounders such as age, pubertal status and objectively assessed PA, we cannot be certain that other unmeasured confounders such as dietary intake or genetic variation do not have any influence in our findings. A strong point of the present study is the use of more than one measure of body fatness, including sophisticated methods like DXA to assess total body fat and abdominal adiposity.

In conclusion, the present study supports and extends previous findings showing the association between fitness and total and central body fat in adolescents, which remained even after adjustment for objectively assessed PA. The results were consistent when using anthropometric and sophisticated measures of total and central fatness, which suggests that skinfolds and waist circumference are valid and useful measures to study adiposity in relation with other factors. In addition, the measurement of fitness should be introduced in large-scale epidemiological studies, because it is an important factor determining health, functionality in activities of daily living and quality of life. Future intervention studies should confirm our findings and determine whether fitness enhancement leads to improvements in body composition.

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What is already known on this topic

- Fitness is considered an important marker of health already in youth. There is little information regarding the association between fitness and body composition measured with sophisticated methods such as dual energy x-ray absorptiometry (DXA), and the few available studies are mainly confined to cardiorespiratory fitness.

What this study adds

- The present study shows that cardiorespiratory fitness and lower body muscular strength are negatively associated with markers of total and central body fat in adolescents even after controlling for age, pubertal status and objectively assessed physical activity.

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Associations of muscular and cardiorespiratory fitness with total and central body fat in adolescents: The HELENA Study

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