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ORIGINAL ARTICLE

Muscular strength and markers of insulin resistance in European adolescents: the HELENA Study

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Abstract The aim of the study was to examine the association of muscular strength with markers of insulin resistance in European adolescents. The study comprised a total of 1,053 adolescents (499 males; 12.5–17.5 years) from ten European cities participating in the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) Cross-Sectional Study. Muscular strength was measured by the handgrip strength and standing long jump tests. Cardiorespiratory fitness was measured by the 20-m shuttle run test. Fasting insulin and glucose were measured and the homeostasis model assessment (HOMA) and quantitative insulin sensitivity check index (QUICKI) indices were calculated. Weight, height, waist circumference and skinfold thickness were measured, and body mass index (BMI) was calculated. In males, the handgrip strength and standing long jump tests were negatively associated with fasting insulin and HOMA (all $P < 0.05$) after controlling for pubertal status, country and BMI or waist circumference. When skinfold thickness was included in the model, the association became non-significant. In females, the standing long jump test was negatively associated with fasting insulin and HOMA (all $P < 0.001$) after controlling for pubertal status, country and surrogate markers of total or central body fat (BMI, waist circumference or skinfold thickness). Findings were retained in males, but not in females after controlling for cardiorespiratory fitness. The findings of the present

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on behalf of the HELENA Study group. The Members of the HELENA study group are given in Appendix.

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study suggest that preventive strategies should focus not only on decreasing fatness and increasing cardiorespiratory fitness but also on enhancing muscular strength.

Keywords Muscular strength · Insulin resistance · Fatness · Adolescence

Introduction

Evidence of the precursors of type 2 diabetes (insulin resistance and glucose intolerance) has been observed in children and adolescents (Karam and McFarlane 2008; Tresaco et al. 2003) making them an increasing public health concern in most of regions of the world (van Dieren et al. 2010; Wild et al. 2004).

Obesity is strongly associated with insulin resistance in children and adolescents (Srinivasan et al. 2002). Likewise, cardiorespiratory fitness has shown to be inversely associated with insulin resistance in children (9–10 years) with high levels of total and central body fat (Ruiz et al. 2007), as well as in obese (Allen et al. 2007; Bell et al. 2007) and non-obese young people (Carrel et al. 2009). These studies highlight the protective role of cardiorespiratory fitness on the association between body fat and insulin levels (Carrel et al. 2009; Carrel and Allen 2009; Steele et al. 2008; Shaibi et al. 2008; Ruiz et al. 2007; Allen et al. 2007; Bell et al. 2007). Other studies have shown, however, that the association between cardiorespiratory fitness and insulin is independent of adiposity (Srinivasan et al. 2002; Allen et al. 2007; Carrel and Allen 2009), suggesting that both cardiorespiratory fitness and adiposity are related to insulin resistance and that their effects could be independent.

Muscular strength is also considered an emergent fitness component in relation to health parameters in young population groups (Ruiz et al. 2009) and adults (Ruiz et al. 2008). Several studies examined the association of muscular strength with metabolic syndrome and insulin resistance in adults (Jurca et al. 2004, 2005; Wijndaele et al. 2007; Chen et al. 2008; Unni et al. 2009) but less is known in young people (Steene-Johannessen et al. 2009; Benson et al. 2006). Benson et al. (2006) examined the association between muscular strength and insulin resistance in a relative small sample ($n = 126$) of children and adolescents from New Zeland (Benson et al. 2006). They observed that children in the highest and middle tertiles of absolute upper body muscular strength were less likely to have high insulin resistance than those in the lowest muscular strength tertile (Benson et al. 2006). More recently, Steene-Johannessen et al. (2009) reported that muscular fitness (a computed score) was negatively associated with a cardiovascular disease risk score including insulin resistance, in a large sample ($n = 1{,}592$) of Norwegian children and adolescents (Steene-Johannessen et al. 2009). Other studies also analysed the association of several muscular strength indexes with metabolic risk scores (Garcia-Artero et al. 2007; Mota et al. 2010), body composition and physical activity (Moliner-Urdiales et al. 2010).

It is of public health interest to better understand whether the association between muscular strength and insulin resistance in young populations is affected by gender, as well as to know more in detail the pattern of this association in a large sample of current generations of European adolescents.

The purpose of this study was to examine the association of muscular strength with markers of insulin resistance after controlling for several potential confounders including total and central body fat in European adolescents from nine different countries.

Methods

The Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-sectional study (HELENA-CSS) is a multicentre study conducted in ten European cities from nine countries designed to obtain reliable and comparable data on nutrition and health-related parameters of a sample of European adolescents aged 12.5–17.5 years (Beghin et al. 2008). Data collection took place between October 2006 and October 2007. The total sample of the HELENA-CSS included 3,546 adolescents with a subset of 1,089 of them providing blood sample. A total of 1,053 adolescents with complete data on serum insulin concentrations, glucose, body mass index (BMI) and waist circumference were included in the present study. The group of adolescents included in the present study was similar when compared to the whole HELENA-CSS group in terms of age, sex, weight, height and muscular strength tests (all $P > 0.2$), except for cardiorespiratory fitness which was significantly higher in the group of females excluded than in those females included (3.9 vs. 3.4 stages, respectively; $P < 0.001$). The study was performed following the ethical guidelines of the Declaration of Helsinki 1964 (revision of Edinburgh 2000), the Good Clinical Practice, and the legislation about clinical research in humans in each of the participating countries. The protocol was approved by the Human Research Review Committees of the involved centres (Beghin et al. 2008).

Physical examination

The protocol for the anthropometric measurements has been described in details elsewhere (Nagy et al. 2008). Weight was measured with an electronic scale (Type SECA 861) to the nearest 0.05 kg in underwear and without shoes. Height was measured with a telescopic height measuring instrument (Type SECA 225) to the nearest 0.1 cm barefoot in the Frankfort plane. BMI was calculated as body weight (kg) divided by height (m) squared (kg/m^2). BMI-z scores were subsequently calculated using the LMS Growth method (Cole et al. 1998). Skinfold thickness was measured with a Holtain Caliper to the nearest 0.2 mm in triplicate in the left side at biceps, triceps, subscapular, suprailiac, thigh, and medial calf (Crymych, UK) (Lohman et al. 1988). Body fat percentage was estimated using the equation reported elsewhere (Slaughter et al. 1988). The same trained investigator made all skinfold thickness measurements in every centre. The intraobserver technical errors of measurement were smaller than 1 mm and reliability greater than 95%. Waist circumference was measured in triplicate at the midpoint between the lowest rib and the iliac crest with an anthropometric tape SECA 200 (Lohman et al. 1988), and was used as a surrogate marker of central body fat. The same trained investigator made all waist circumference measurements in every centre, and the reliability was greater than 95%. Inter-observer reliability for skinfold and circumferences was higher than 90% (Nagy et al. 2008). Pubertal stage was assessed by a physician according to Tanner and Whitehouse (1976).

Muscular strength

Physical fitness characteristics of the study sample, as well as the procedures used for assessing it in the HELENA-CSS, have been published elsewhere (Ortega et al. 2011). The tests are valid, reliable and feasible to be used in population-based studies (Artero et al. 2010; Ortega et al. 2008; Ruiz et al. 2009; Castro-Pinero et al. 2010). We assessed upper and lower body muscular strength with the following tests:

Handgrip strength test (upper body muscular strength)

A hand dynamometer with adjustable grip was used (TKK 5101 Grip D; Takey, Tokio Japan). The adolescent squeezed gradually and continuously for at least 2 s, performing the test with the right and left hand alternatively, using the optimal grip-span. The optimal grip-span was calculated according to hand size using an equation that we developed specifically for adolescents (Ruiz et al. 2006). The maximum score in kilograms for each hand was recorded. The sum of the maximum scores achieved by left and right hands was used in the analysis.

Standing long jump test (lower body explosive muscular strength)

The participant stands behind the starting line and was instructed to push off vigorously and jump as far as possible. The distance was measured from the take-off line to the point where the back of the heel nearest to the take-off line lands on the mat. The result was recorded in centimeters (cm).

Both tests were performed twice and the best score was retained.

Cardiorespiratory fitness

It was measured by the progressive 20-m shuttle run test (Leger et al. 1984). This test required subjects to run back and forth between two lines set 20 m apart following a running pace determined by audio signals and with an initial speed of 8.5 km h^{-1} increasing by 0.5 km h^{-1} every minute (1 min equals 1 stage). The test was finished when the adolescent failed to reach the end lines concurrent with the audio signals on two consecutive occasions and the final score was computed as the number of stages completed (precision of 0.5 stages).

Blood samples

A detailed description of the blood analysis has been reported elsewhere (Gonzalez-Gross et al. 2008). Serum concentrations of glucose and insulin were measured after an overnight fast. The homeostasis model assessment (HOMA) was calculated (Matthews et al. 1985) as fasting insulin (μIU/mL) × fasting glucose (mmol/l)/22.5. To convert glucose in mg/dL to mmol/L, the value of glucose in mg/dL multiplied by a factor of 0.05551 and to convert insulin values in μIU/mL to pmol/l multiply by 6.94, before insertion into the HOMA equation. A quantitative insulin sensitivity check index (QUICKI) was calculated as QUICKI = 1/[log insulin (μIU/mL) + log glucose (mg/dL)] (Katz et al. 2000).

Statistical analysis

The data are presented as mean ± standard deviation, unless stated otherwise. To achieve normality, insulin, waist circumference and total body fat were transformed to the natural logarithm, and HOMA was raised to the power of 1/3. To examine the association between muscular strength, markers of insulin resistance and surrogate markers of body fat, we conducted partial correlation analyses controlling for pubertal status.

Multiple linear regression models were used to study the association of muscular strength with markers of insulin resistance after controlling for pubertal status, country and surrogate markers of total and central body fat. Country was entered into the models as a dummy variable. Interaction products of gender and surrogate markers of body fat in the association of muscular strength with markers of insulin resistance were explored. There was an interaction

Table 1 Descriptive characteristics of the study participants

	All (n = 1,053)	Males (n = 499)	Females (n = 554)	P value
Age (years)	14.9 ± 1.2	14.9 ± 1.3	14.9 ± 1.2	0.716
Puberal status (I/II/III/IV/V)[a]	1/6/20/44/29	0/5/21/44/30	2/8/20/42/28	
Weight (kg)	58.9 ± 12.4	62.1 ± 14.0	56.0 ± 10.2	<0.001
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	<0.001
BMI (kg/m^2)	21.4 ± 3.6	21.4 ± 3.8	21.3 ± 3.4	0.972
BMI-z score	−0.02 ± 0.97	−0.02 ± 0.95	−0.02 ± 0.99	0.951
Waist circumference (cm)[b]	72.4 ± 8.8	74.5 ± 9.1	70.6 ± 8.0	<0.001
Six skinfold thickness (mm)[b]	90.2 ± 39.6	76.0 ± 39.2	102.8 ± 35.7	<0.001
Glucose (mmol/L)	5.1 ± 0.4	5.2 ± 0.4	5.0 ± 0.4	<0.001
Insulin (μlU/mL)[b]	10.1 ± 7.6	10.1 ± 8.7	10.2 ± 6.4	0.019
HOMA[c]	2.3 ± 1.9	2.3 ± 2.2	2.3 ±1.6	0.581
QUICKI	0.14 ± 0.01	0.15 ± 0.01	0.15 ± 0.01	0.106
Handgrip strength (kg)[d]	61.6 ± 18.1	72.7 ± 19.1	52.2 ± 9.9	<0.001
Handgrip/body weight	1.05 ± 0.24	1.18 ± 0.25	0.94 ± 0.18	<0.001
Standing long jump (cm)	163.1 ± 35.3	184.8 ± 32.7	144.9 ± 25.4	<0.001
Cardiorespiratory fitness (stage)	4.8 ± 2.8	6.3 ± 2.8	3.4 ± 1.8	<0.001

All values are mean ± standard deviation, or [a]percentages

BMI body mass index, *HOMA* homeostasis model assessment *QUICKI* quantitative insulin sensitivity check index

Non-transformed data are presented in this table, but analyses were performed on [b]log-transformed data or [c]data transformed to the power of 1/3

[d] Sum of the scores of left and right hands

effect for gender but not for surrogate markers of body fat, therefore all the analyses were performed separately for females and males but not for body fat levels. Three different models were conducted: model I included pubertal status, country and BMI as covariates, model II included pubertal status, country and waist circumference as covariates, model III included pubertal status, country and skinfold thickness as covariates.

The association between muscular strength (quartiles) and markers of insulin resistance was assessed by one-way analysis of covariance with handgrip/body weight and standing long jump as fixed factors, and HOMA as dependent variables. Pubertal status, country, and surrogates markers of body fat were entered as covariates.

Additional analyses further controlling for cardiorespiratory fitness (stages) were performed. BMI-z scores were included into the models instead of BMI in secondary analyses. The analyses were conducted using the Statistical Package for Social Science (SPSS, v. 15.0 for Windows; SPSS Inc., Chicago, IL, USA) and the level of significance was set to 0.05.

Results

Valid data on the handgrip strength, standing long jump tests and skinfold thickness were available in 93% (n = 975), 91% (n = 963) and 93% (n = 981) of adolescents, respectively. Table 1 shows the descriptive characteristics of the study sample. Males had significantly higher waist circumference, glucose and muscular strength than females. Females had significantly higher levels of insulin and skinfold thickness than males. HOMA and QUICKI mean levels were similar for both males and females. Partial correlations among the study variables are displayed in Table 2.

The results of the linear regression models showing the association of muscular strength with markers of insulin resistance are presented in Tables 3 and 4 for males and females, respectively. In males, the handgrip strength test was negatively associated with fasting insulin and HOMA after controlling for pubertal status, country and BMI (Model I) or waist circumference (Model II) (all $P < 0.05$). The standing long jump test was negatively associated with fasting insulin and HOMA after controlling for waist circumference (Model II). There were no significant associations between muscular strength and markers of insulin resistance after controlling for skinfold thickness (Table 3, Model III). In females, the standing long jump test was negatively associated with fasting insulin and HOMA and positively associated with QUICKI (all $P < 0.001$) after controlling for pubertal status, country and surrogate markers of body fat (Models I, II and III) (Table 4).

HOMA was analyzed by quartiles of handgrip/body weight (Fig. 1a) and standing long jump tests (Fig. 1b). The values (range) for the handgrip strength and standing long

Table 2 Partial correlations between muscular strength, markers of insulin resistance and surrogate markers of body fat, controlling for pubertal status

Females	Males										
	Muscular strength				Markers of insulin resistance				Surrogate markers of body fat		
	Cardiorespiratory fitness	Handgrip	Handgrip/body weight	Standing long jump	Insulin[a]	HOMA[b]	Glucose	QUICKI	WC[a]	Skinfold thickness[a]	BMI
Cardiorespiratory fitness		−0.041	0.188[c]	0.341[c]	−0.225[c]	−0.236[c]	−0.174[c]	0.230[c]	−0.310[c]	−0.381[c]	−0.327[c]
Handgrip	0.125[d]		0.603[c]	0.419[c]	0.071	0.058	−0.006	−0.075	0.430[c]	0.08	0.424[c]
Handgrip/body weight	0.322[c]	0.657[c]		0.469[c]	−0.249[c]	−0.244[c]	0.004	0.230[c]	−0.495[c]	−0.591[c]	−0.528[c]
Standing long jump	0.439[c]	0.204[c]	0.512[c]		−0.156[d]	−0.163[d]	−0.097	0.154[d]	−0.156[d]	−0.430[c]	−0.169[c]
Insulin[a]	−0.303[c]	−0.011	−0.205[c]	−0.289[c]		0.972[c]	0.270[c]	−0.977[c]	0.350[c]	0.422[c]	0.395[c]
HOMA[b]	−0.307[c]	−0.016	−0.213[c]	−0.270[c]	0.974[c]		0.379[c]	−0.932[c]	0.338[c]	0.413[c]	0.392[c]
Glucose	−0.103	−0.085	−0.062	0.016	0.217[c]	0.357[c]		−0.386[c]	0.077	0.158[d]	0.102[d]
QUICKI	0.296[c]	0.028	0.188[c]	0.269[c]	−0.982[c]	−0.955[c]	−0.340[c]		−0.342[c]	−0.423[c]	−0.380[c]
WC[a]	−0.224[c]	0.291[c]	−0.383[c]	−0.298[c]	0.273[c]	0.253[c]	−0.059	−0.247[c]		0.773[c]	0.906[c]
Skinfold thickness[a]	−0.373[c]	0.082	−0.527[c]	−0.422[c]	0.276[c]	0.239[c]	−0.067	−0.257[c]	0.690[c]		0.792[c]
BMI	−0.306[c]	0.282[c]	−0.350[c]	−0.343[c]	0.264[c]	0.237[c]	−0.081	−0.235[c]	0.831[c]	0.769[c]	

BMI body mass index, *HOMA* homeostasis model assessment, *QUICKI* quantitative insulin sensitivity check index, *WC* waist circumference

[a] Log-transformed data

[b] Power of 1/3-transformed data

[c] $P < 0.01$

[d] $P < 0.05$

Table 3 Multiple linear regression models showing the association of muscular strength with markers of insulin resistance in male European adolescents

Variables		Model I			Model II			Model III		
Dependent	Independent	*β*	R^2	*P*	*β*	R^2	*P*	*β*	R^2	*P*
Insulin[a]	Handgrip	−0.139	0.207	**0.029**	−0.149	0.190	**0.022**	−0.005	0.210	0.936
	Handgrip/body weight	−0.097	0.203	0.090	−0.132	0.190	**0.021**	−0.026	0.210	0.690
	Standing long jump	−0.092	0.228	0.071	−0.103	0.191	**0.045**	0.029	0.216	0.601
HOMA[b]	Handgrip	−0.152	0.203	**0.017**	−0.156	0.179	**0.017**	−0.008	0.202	0.896
	Handgrip/body weight	−0.102	0.142	**0.041**	−0.142	0.180	**0.014**	−0.036	0.202	0.537
	Standing long jump	−0.097	0.201	0.058	−0.112	0.180	**0.031**	0.020	0.209	0.719
QUICKI	Handgrip	0.107	0.198	0.093	0.120	0.187	0.066	−0.026	0.213	0.665
	Handgrip/body weight	0.077	0.196	0.182	0.109	0.188	0.058	−0.005	0.213	0.910
	Standing long jump	0.090	0.201	0.079	0.099	0.191	0.056	−0.036	0.220	0.517

Model I included pubertal status, country and body mass index as covariates. Model II included pubertal status, country and waist circumference as covariates. Model III included pubertal status, country and skinfold thickness as covariates

HOMA homeostasis model assessment, *QUICKI* quantitative insulin sensitivity check index

Bold values indicate significance for the different multiple linear regression models

jump tests were 28.70–127.10 kg and 75–270 cm, respectively, in males, and 18.40–89.20 kg and 46–217 cm, respectively, in females. The cut offs for the handgrip/body weight (quartiles) were 1.01, 1.20 and 1.35 in males, and 0.82, 0.93 and 1.05 in females.

HOMA showed a negative association with muscular strength in both genders. Particularly in females, HOMA was significantly higher in quartile 1 compared to quartiles 3 or 4 for handgrip/body weight (Fig. 1a) and standing long jump (Fig. 1b) after controlling for several confounders including all the surrogate markers of body fat (all $P < 0.05$). In males, a similar trend was observed across quartiles of both muscular strength tests but statistically significant differences were observed after controlling for waist circumference (in both tests) and for BMI (in the standing long jump test) (all $P < 0.05$).

To account for the effect of weight-bearing tests, additional analyses using standing long jump multiplied by weight were undertaken; this, however, did not affect the results (data not shown). When the analyses were addition-

Table 4 Multiple linear regression models showing the association of muscular strength with markers of insulin resistance in female European adolescents

Variables		Model I			Model II			Model III		
Dependent	Independent	*β*	R^2	*P*	*β*	R^2	*P*	*β*	R^2	*P*
Insulin[a]	Handgrip	−0.037	0.138	0.454	−0.069	0.166	0.163	−0.027	0.155	0.584
	Handgrip/body weight	−0.070	0.140	0.196	−0.058	0.165	0.265	−0.084	0.159	0.138
	Standing long jump	−0.193	0.156	**<0.001**	−0.176	0.179	**<0.001**	−0.181	0.168	**<0.001**
HOMA[b]	Handgrip	−0.024	0.120	0.638	−0.056	0.148	0.265	−0.014	0.137	0.783
	Handgrip/body weight	−0.064	0.122	0.247	−0.053	0.147	0.315	−0.086	0.141	0.131
	Standing long jump	−0.188	0.141	**<0.001**	−0.173	0.162	**<0.001**	−0.185	0.154	**<0.001**
QUICKI	Handgrip	0.030	0.128	0.551	0.061	0.155	0.224	0.024	0.147	0.631
	Handgrip/body weight	0.056	0.129	0.304	0.043	0.154	0.417	0.065	0.149	0.249
	Standing long jump	0.181	0.144	**<0.001**	0.165	0.166	**0.001**	0.170	0.159	**0.001**

Model I included pubertal status, country and body mass index as covariates. Model II included pubertal status, country and waist circumference as covariates. Model III included pubertal status, country and skinfold thickness as covariates

HOMA homeostasis model assessment, *QUICKI* quantitative insulin sensitivity check index

Bold values indicate significance for the different multiple linear regression models

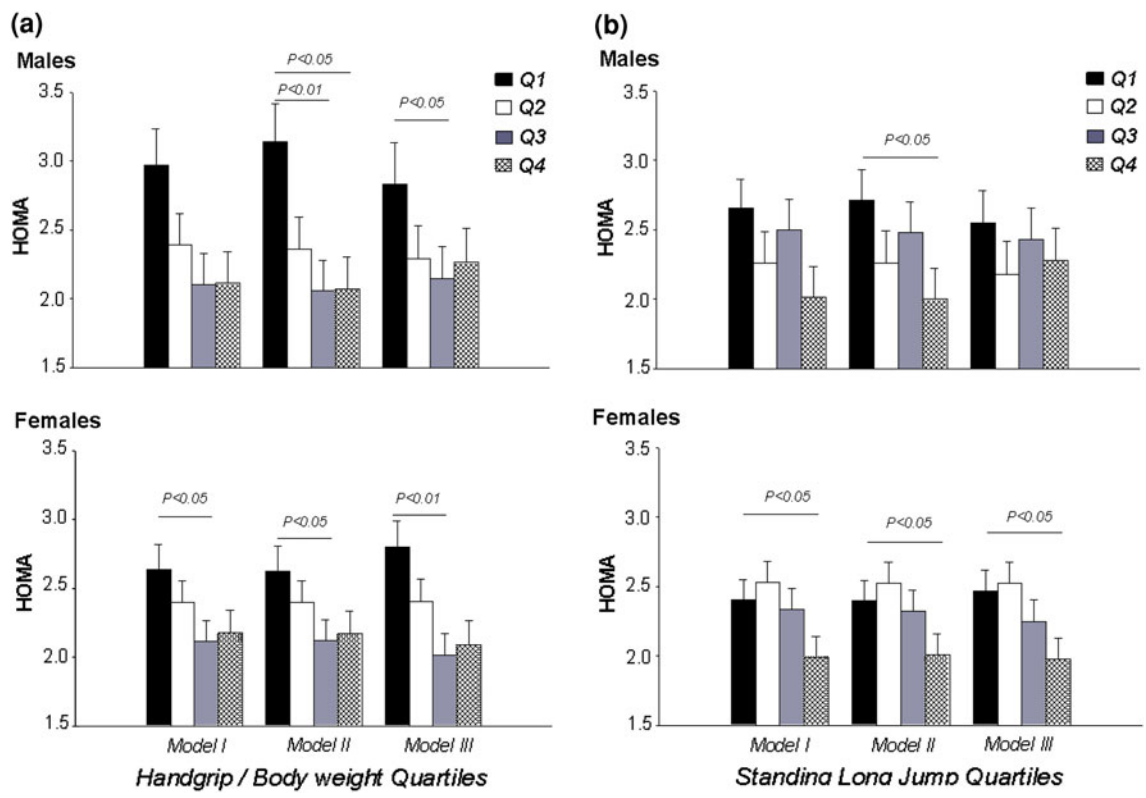

Fig. 1 Differences in HOMA across muscular strength quartiles (**a** handgrip strength test; **b** standing long jump test) in males and females. Model I included pubertal status, country and body mass index as covariates. Model II included pubertal status, country and waist circumference as covariates. Model III included pubertal status, country and skinfold thickness as covariates

ally controlled for cardiorespiratory fitness the associations of handgrip with insulin and HOMA remained significant in males (models I and II; all $P < 0.05$), while in females, the associations became non-significant. The results remain the same after the inclusion of BMI-z scores into the models instead of BMI (data not shown).

Discussion

The main findings of this study indicate that, in females, muscular strength, especially lower body muscular strength, is negatively associated with markers of insulin resistance after controlling for several confounders including total and central body fat (BMI and skinfold thickness, and waist circumference, respectively), yet, these associations become non-significant when cardiorespiratory fitness is taken into account. Muscular strength in males, especially upper body muscular strength, is also negatively associated with markers of insulin resistance after controlling for several confounders including BMI or waist circumference, yet the association is attenuated once the analyses are controlled for skinfold thickness.

Our findings agree with other studies (Benson et al. 2006; Steene-Johannessen et al. 2009). Benson et al. (2006) analyzed the association between muscular strength and insulin resistance in a relative small sample ($n = 126$) of children and adolescents (12.1 years; range 10–15 years) from New Zealand (Benson et al. 2006). Upper body muscular strength was assessed with 1 repetition maximum (RM) supine bench press (progressive repetition maximal lift), and lower body strength was assessed with a 1RM incline seated leg press. They observed a negative association between muscular strength (a combination of the upper and lower body muscular strength) and insulin resistance (HOMA) (Benson et al. 2006). However, they did not conduct gender-specific analysis, probably, due to the relative small sample size. In our study, the analyses were performed separately by gender ($n = 499$ males and $n = 554$ females) and using two relatively simple, valid, reliable, and safe field-based muscular strength tests (Ruiz et al. 2011a). Our findings showed a negative association of muscular strength (upper body muscular strength in males and lower body muscular strength in females) with markers of insulin resistance in both genders. These results suggest a gender-specific pattern for the association between muscular strength and insulin resistance due to the fact that different tests were associated for each sex. However, the difference in insulin levels between sexes as well as the fact that insulin resistance was associated with upper body strength in males and with upper and lower body strength in females is intriguing and warrants further investigation (Benson et al. 2006). It is possible that the well known higher physical activity levels in males versus females (Ruiz et al. 2011b), the differences in hormone levels and maturation between sexes (Rogol 2010), and the higher amount of body fat in females compare to males (Jiménez-Pavón et al. 2011; Rogol 2010) could affect, to some extent, the association of muscular strength with insulin resistance. In fact, it is possible that the underlying physiologic mechanism could be the joint effect of the mentioned factors and a higher fat-free mass in males compared to females (Moliner-Urdiales et al. 2010).

To note is that in males, the association between upper body muscular strength and insulin resistance disappeared after controlling for skinfold thickness, which suggest that handgrip strength could partially represents a surrogate of lean body mass. However, it is of interest that those males being in the first quartile of upper body muscular strength had a biological higher insulin resistance level compared to those in the last quartile after controlling for skinfold thickness. Steene-Johannessen et al. (2009) observed an inverse association between muscular strength (a score computed from the handgrip, standing long jump, sit-up and Biering-SØrensen tests) and a cardiovascular disease risk score including insulin resistance (HOMA), in a large sample ($n = 1{,}592$) of Norwegian children and adolescents. This inverse association was independent of cardiorespiratory fitness in both males and females. By contrast, our study showed that after controlling for cardiorespiratory fitness the associations between muscular strength and insulin resistance remained significant only in males. The discrepancies between studies might be attributable to the choice of the dependent variable (cardiovascular disease risk score vs. a single component such as insulin resistance). Artero et al. (2011) observed in the HELENA-CSS that muscular (a score of several tests) and cardiorespiratory fitness are inversely and independently associated with clustered metabolic risk, and specially those adolescents in the lower quartile of muscular fitness had a higher clustered metabolic risk than their counterparts (Artero et al. 2011). Our findings show a similar pattern for insulin resistance and add the gender-specific dimension, as well as controls for more potential confounders such as surrogate markers of body fat.

In adults, it has been suggested that resistance exercises might protect against insulin resistance by an increase in muscle quantity and an increase in skeletal muscle insulin action, indicating qualitative muscle adaptations (Koopman et al. 2006). Several studies examined the effect of resistance exercise and/or nutrition (Shaibi et al. 2006; Davis et al. 2009) on insulin sensitivity in overweight adolescents, and showed concomitant increases of muscular strength and insulin sensitivity after a 16-week intervention training in the pilot study (Shaibi et al. 2006) but not in the overall study (Davis et al. 2009). In adults, it has been suggested that higher muscular strength and muscle mass might be relevant factors against insulin resistance (Holten et al. 2004; Koopman et al. 2006; Rattarasarn et al. 2010), while in adolescents, the concrete mechanisms are not yet established.

Skeletal muscle is the major site of glucose disposal in the euglycemic state, and muscular strength is related to muscle size (Rattarasarn et al. 2010). We hypothesized that those adolescents with a higher levels of muscular strength are also those playing activities that increase muscular strength and consequently insulin sensitivity (Shaibi et al. 2006). The possibility to increase muscular strength without a concomitant increase in muscle mass in adolescents has also been stated (Shaibi et al. 2006) which could partially explain the different pattern observed in our study regarding the relationship of muscular strength with insulin resistance between genders. However, our study was not designed to analyse this issue.

The present study has several limitations. The cross-sectional nature of this study limits the ability to determine any causality in the results. Randomized controlled trials and prospective studies focused on clarifying the specific role of changes in muscular strength manifestations are needed. Moreover, it would also be useful to better understand the possible different patterns of this relationship between ethnicities. The strengths of our study include the availability of standardize measures of insulin resistance, muscle strength, cardiorespiratory fitness and fat mass in a well sex-balanced and heterogeneous sample of European healthy adolescents from nine countries.

Conclusion

Our cross-sectional observations suggest that muscular strength is negatively associated with markers of insulin resistance after controlling for several confounders including total and central body fat (BMI and waist circumference in both genders and skinfold thickness only in females). Specifically, upper body muscular strength in males and lower body muscular strength in females show the strongest association with markers of insulin resistance. In males, however, the association between muscular strength and markers of insulin resistance disappears when controlling for skinfold thickness. In addition, these associations in males are independent of cardiorespiratory fitness, while in females the associations of lower body strength and cardiorespiratory fitness with markers of insulin resistance seem to be collinear.

Preventive strategies should focus not only on decreasing fat mass and increasing cardiorespiratory fitness but also on enhancing muscular strength. In fact, the recent position statement from the National Strength and Conditioning Association and the American Academy of Pediatrics recommends a resistance training frequency of 2–3 times per week on non-consecutive days for children and adolescents (Faigenbaum et al. 2009; McCambridge and Stricker 2008).

Ethical standard The study complies with the current laws of the countries involved.

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Conflict of interest The authors declare that they have no conflict of interest.

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