Muscle strength field-based tests to identify European adolescents at risk of metabolic syndrome: The HELENA study

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ABSTRACT

Objectives: To determine whether handgrip strength (HG) and/or standing long jump (SLJ) are capable of detecting risk of metabolic syndrome (MetS) in European adolescents, and to identify age- and sex-specific cut points for these tests.

Design: Cross-sectional study.

Methods: Participants included 969 (aged 12.5-17.5 years old) adolescents from 9 European countries (*n*=520 girls). Absolute and relative HG and SLJ tests were used to assess upper and lower muscle strength, respectively. MetS status was determined using the age- and sex-specific cut points proposed by Jolliffe and Janssen´s, Additionally, we computed a continuous cardiometabolic risk index with the average z-score of four cardiometabolic risk factors: Wait circumference, mean arterial pressure, triglycerides/high-density lipoprotein cholesterol, and fasting insulin.

Results: The prevalence of MetS was 3.1% in European adolescents. Relative HG and absolute SLJ were the best tests for detecting the presence of MetS (Area under the receiver operating characteristic (*AUC*)=0.799, *95%CI*:0.773-0.824; and *AUC*=0.695 *95%CI:*0.665-0.724), respectively) and elevated cardiometabolic risk index (*AUC*=0.873, *95%CI*:0.838-0.902; and *AUC*=0.728 *95%CI*:0.698-0.756), respectively) and, regardless of cardiorespiratory fitness. We provide age- and sex-specific cut points of upper and lower muscle strength for European adolescents to identify the presence of MetS and elevated cardiometabolic risk index.

Conclusions: The proposed health-related cut points could be used as a starting point to define health-related levels of upper and lower muscle strength in adolescents. Likewise, the diagnostic statistics provided herein can be used to offer feedback to adolescents, parents, and education and health professionals about what it means to meet or fail test standards.

Key words: Muscle fitness. Cardiometabolic risk. Adolescents

1. Introduction

Metabolic syndrome (MetS) has become a major health challenge worldwide with its prevalence increasing in concert with obesity and sedentary lifestyles.[1] MetS is defined as clustering of dichotomous or continuous cardiometabolic risk factors, which includes dyslipidemia (triglycerides and cholesterol), hypertension, glucose intolerance, and total and/or central adiposity.[1] MetS affects both youth and adults and has been associated with cardiovascular disease and type 2 diabetes,[2] as well as with all-cause mortality in non-diabetic individuals and in adult populations.[1] Given that MetS and many of its features track from childhood into adulthood,[2] early detection and diagnosis of MetS in youth is necessary to develop effective prevention programs.

Both upper and lower body muscle strength levels are considered important markers of cardiometabolic health in children and adolescents.[3] Moreover, muscle strength is associated with cardiometabolic risk factors, independently of cardiorespiratory fitness.[4] The Institute Of Medicine[5] recommended that a survey of health-related physical fitness in youth should include upper and lower body muscle strength measurements. Furthermore, this Institute called for the need of determining health-related muscle strength cut points for children and adolescents for identifying youth who may benefit from primary and secondary cardiometabolic prevention programming.[5]

The Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study is a multicenter, cross-sectional study performed in nine European countries primarily designed to obtain reliable and comparable data on nutrition and health-related parameters of a relatively large sample of European adolescents aged 12.5–17.5.[6] The HELENA study collected data on upper and lower body muscle strength measured by means of the handgrip strength (HG) and the standing long jump (SLJ) tests. Both tests have been proposed to assess upper and lower body muscle strength levels in European youth.[7] In addition, the HELENA study also collected data on MetS and other relevant clinical and socio-demographic features in a large sample of European adolescents, thus providing a great opportunity (i) to determine whether the HG and/or SLJ tests are capable of detecting risk of MetS in European adolescents, and (ii) to identify age- and sex-specific cut points for these tests.

2. Methods

Adolescents volunteered to participate in the HELENA study, a multicenter cross-sectional study on lifestyle and nutrition, conducted in 10 European cities (cluster) from 9 European countries (Vienna, Ghent, Lille, Dortmund, Athens, Heraklion, Pécs, Rome, Zaragoza and Stockholm).[6]

The HELENA study sample comprised 3,528 adolescents (52% girls) aged 12.5– 17.5 years old. Blood sampling was randomly performed in one-third of the recruited adolescents (*n*=1,089). The present study included adolescents who had complete data on body mass index (BMI), muscle strength, cardiorespiratory fitness, and the cardiometabolic risk factors considered in these analyses: waist circumference (WC), diastolic and systolic blood pressure, triglycerides (TG), high-density lipoprotein cholesterol (HDL), and fasting glucose and insulin levels. The sample sizes vary by analysis (see all tables), but 1,574 and 1567 boys contributed physical fitness data on HG and SLJ, respectively, and 1,718 and 1702 girls contributed physical fitness data on HG and SLJ, respectively, whereas 449 boys and 520 girls also had blood data for the analyses.[8]

The study was approved by the Research Ethics Committees of each study site, and was performed following the ethical guidelines of the Declaration of Helsinki 1964 (revision of Edinburgh 2000). A written informed consent was obtained from the parents of the adolescents and the adolescents themselves.

Body mass index

Body mass was measured in underwear without shoes using an electronic scale (Type SECA 861, Hamburg, Germany) to the nearest 0.1 kg. Stature was measured barefoot to the nearest 0.1 cm using the Frankfort horizontal plane and a stadiometer (Type SECA 225, Hamburg, Germany). BMI was calculated as body mass (kg) / stature (m)^2. The International Obesity Task Force BMI standards were used to categorize children as normal weight or overweight/obese.[9]

Physical Fitness

Upper and lower body muscle strength levels were measured by the HG and the SLJ tests,[7] respectively. Both test are valid[10], reliable[11], feasible and safe[12] to be used both at population level and in the school-setting.[7] A hand dynamometer with an adjustable grip (TKK 5101 Grip D, Takey, Tokyo, Japan) was used for the HG test. The adolescent squeezed the dynamometer continuously for at least 2 seconds, alternatively with right and left hands, with the elbow in full extension. The grip-span of the dynamometer was adjusted according to the hand size of the adolescent. The test was performed twice, allowing a 1-minute rest between the measurements to avoid local muscle fatigue, and the maximum score for each hand was recorded in kilograms as described elsewhere.[13] The average of the scores achieved by the left and right hands was used in the analyses to have an overall measure of the handgrip strength.[13] The SLJ was performed from a starting position immediately behind a line, standing with feet approximately shoulder's width apart, and the adolescent jumped as far forward as possible, landing with their feet together. The test was performed twice, with 1-minute rest between the measurements, and the longest distance achieved was recorded in centimeters. Before conducting the tests, adolescents had a familiarization trial. Nevertheless, as these tests are commonly used in the school setting to measure fitness performance, adolescents were rather familiarized. We converted HG and SLJ to relative scores by expressing HG as strength divided by body mass [strength (kg) / body mass (kg)] and expressing SLJ as jump distance multiplied by body mass [jump distance (cm) x body mass (kg)].

In order to determine the potential influence of cardiorespiratory fitness (a well-known important marker of health in adolescents[3] on the association of HG and/or SLJ with the risk of MetS, we decided to control the analysis by this variable. We assessed cardiorespiratory fitness by the 20 m shuttle run test and the maximum oxygen consumption (VO_{2max}, ml/kg/min) by the equation reported by Léger et al.[14] Each adolescent was grouped into a cardiorespiratory fitness status (low or high) according to the FITNESSGRAM standards Healthy Fitness Zone as follows: low corresponds to the "needs improvement" category, and high correspond to the "healthy fitness zone".[15] All these fitness tests have shown to be valid and reliable in children and adolescents.[10, 11]

Cardiometabolic risk factors

Waist circumference was measured in triplicate using an anthropometric tape (SECA 200) as the midpoint between the lowest rib and the iliac crest.[16] Diastolic and systolic blood pressure were measured after being seated in a quiet room for 10 min with their back supported and feet on the ground. Two diastolic and systolic blood pressure readings were taken with a 10-min interval of quiet rest. The lower value of the two measurements was used in the analysis. We calculated the mean arterial pressure as [diastolic blood pressure + (0.333 x (systolic blood pressure - diastolic blood pressure))]. A detailed description of the blood samples' analysis has been reported elsewhere.[17] Venous blood was obtained by venipuncture after an overnight fast. Serum TG, HDL, and fasting glucose were measured on a Dimension RxL clinical chemistry system (Dade Behring, Schwalbach, Germany) using enzymatic methods. Fasting insulin concentrations were measured by a solid-phase two-site chemiluminescent immunometric assay, using an Immulite 2000 analyzer (DPC Biermann GmbH, Bad Nauheim, Germany).

MetS status was also determined using WC, diastolic and systolic blood pressure, TG, HDL, and fasting glucose with the definition by Jolliffe and Janssen reported in 2007.[18] This pediatric definition was created using growth curves to back-extrapolate the National Cholesterol Education Program/Adult Treatment Panel II adult values for adolescents. The participants were considered as having an individual elevated cardiometabolic risk factor if they had a high WC, either systolic or diastolic blood pressure, TG, HDL, or fasting glucose. Adolescents with 3 or more elevated cardiometabolic risk factors were considered as having MetS.

Additionally, all cardiometabolic risk factors were expressed as age- and sex-specific z-scores based on the current sample to account for changes during growth and maturation. Further, a continuous cardiometabolic risk index was computed as the average z-score of four cardiometabolic risk factors (WC, mean arterial pressure, TG/HDL ratio, and fasting insulin). The adolescents were categorized as having elevated cardiometabolic risk if their cardiometabolic risk index was one standard deviation above the mean for each of the four markers. This cardiometabolic risk index methodology has been previously validated in children and adolescents.[19]

The descriptive data are shown as mean and standard deviation unless otherwise indicated, and the sexes were compared with independent samples t-tests and chi-square tests of independence. Receiver operating characteristic (ROC) analyses were completed for all four muscle strength parameters: absolute HG, relative HG (HG / body mass), absolute SLJ, and relative SLJ (SLJ x body mass). The Least Mean Square (LMS) method[20] was used to create age- and sex-specific z-scores and were used in the main analysis.

In the current study, we constructed ROC curves to detect MetS and elevated cardiometabolic risk index from the four muscle strength parameters. The resulting ROC curves and data provide several key variables that aid in identifying appropriate thresholds, such as: area under the ROC curve (*AUC*), sensitivity, specificity, Youden Index (i.e. the sum of sensitivity and specificity minus one, and is the most commonly used indicator of an ideal cut point on the ROC curve), positive predictive value (*PPV*), negative predictive value (*NPV*), and the diagnostic odds ratio (*OR*).[21] In terms of this analysis, *AUC* is a test of global discriminatory accuracy indicating how well the muscle strength z-score can differentiate between MetS vs. no-MetS and elevated vs. low cardiometabolic risk index.

The ROC curves were initially constructed separately by sex, and then for the total sample to identify the impact of combining both sexes. After creating the curves, the four tests of muscle strength were compared to identify the best tests/metrics to use for the intended purpose: whether absolute or relative HG, and absolute or relative SLJ. Pairwise comparisons of the *AUC* values were made using the methods outlined by Hanley and McNeil.[22] Then, to select the ideal cut points for each of the four tests, we primarily made decisions based on the Youden Index, but we also gave consideration to the *PPV*, *NPV*, and diagnostic *OR* for each threshold. After selecting the ideal cut points, to determine how the predictive utility of the thresholds would be impacted by cardiorespiratory fitness, we used logistic regression to estimate the odds of MetS and elevated cardiometabolic risk index in youth with muscle strength cut points (low vs. high levels) in two models: unadjusted or adjusted for cardiorespiratory fitness status. The LMS percentile curves and ROC curves were constructed using LMS ChartMaker Pro (version 2.3). All other analyses were done using IBM SPSS (version 20.0). The alpha level for all analyses was set at $p \leq 0.05$.

3. Results

Boys had higher levels of absolute and relative upper and lower body muscle strength than girls (all $p < 0.05$), as well as higher WC, systolic blood pressure, mean arterial pressure, and fasting glucose (all $p < 0.05$). However, girls had higher levels of TG and HDL than boys (both $p < 0.05$). The prevalence of MetS as well as the elevated cardiometabolic risk index was similar in boys and girls (**Table S1**).

Table S2 shows the *AUC* and pairwise comparisons of the four muscle strength parameters calculated. All *AUCs*, except for absolute HG to predict MetS in girls, were significantly different from a non-informative test (all $p < 0.05$), indicating that any of the four parameters could be used to differentiate between those with MetS and with elevated cardiometabolic risk index. The *AUC* values were higher for boys than for girls, and the *AUC* for specific curves ranged from moderately accurate (0.873 for boys' relative HG) to less accurate (0.539 for girls' absolute HG). For both boys and girls, the relative HG was a significantly better indicator of MetS, and the elevated cardiometabolic risk index (i.e., ≥1 z-score) than absolute HG. Furthermore, there was no difference in the *AUC* between absolute and relative SLJ. In general, the more informative iterations of the muscle strength parameters were relative HG and absolute SLJ.

The selected thresholds for each muscle strength test to identify an elevated cardiometabolic risk index are shown in **Table 1**. Each cut point selected as 'ideal' had the highest Youden Index of the potential thresholds, except girls' absolute SLJ. For girls' absolute SLJ, the highest Youden Index was found at a -0.0183 z-score (approximately the 49^{th} percentile). However, the 5^{th} highest Youden Index (z-score = -0.846) had a higher specificity, *PPV*, and diagnostic *OR*. Because it afforded these advantages and was still within the top 1% of Youden Index scores it was selected instead.

Table 2 depicts the selected thresholds for each muscle strength test to identify MetS. Each 'ideal' cut point had the highest Youden Index available except two boys' thresholds, relative HG and absolute SLJ. For both, the cut point with the highest Youden Index was relatively unbalanced, a very low specificity for relative HG (z-score = -0.4847) and a high specificity for absolute SLJ (z-score = -1.5557). The relative HG and absolute SLJ cut points selected for boys where those with the higher sensitivities, specificities, *PPV*, *NPV*, and odds ratios (z-score = -1.127 and -0.890, respectively). Moreover, Youden Index scores were near the top of the possible cut points. The diagnostic *OR*s were higher for boys than girls. It should be noted that the cut points for absolute HG and relative SLJ are reversed from what would be considered intuitive. Higher absolute HG and relative SLJ scores were more indicative of greater odds of having MetS or an elevated cardiometabolic risk index.

Table 3 outlines the selected age- and sex-specific scores for relative HG and absolute SLJ for boys and girls derived in the current study. These approximate the 25th and 20th percentiles using the LMS parameters for relative HG and absolute SLJ, respectively. These final cut points are based on the 'ideal' cut points for boys and girls from Tables 2 and 3, where the relative HG cut points for boys and girls were the 25.1th and 26.7th percentiles, and the absolute SLJ cut points were the 21.5th and 21.3rd.

Adolescents with low relative HG scores were more likely to have MetS and elevated cardiometabolic risk index (*OR*: 6.2, 95% *CI*: 2.9-13.4; and *OR*: 8.5, 95% *CI*: 5.0-14.7, respectively) than those with scores at or above the determined cut points. Likewise, boys and girls with low absolute SLJ scores were more likely to have MetS and elevated cardiometabolic risk index (*OR*: 4.5, 95% *CI*: 2.3-9.4; and *OR*: 5.8, 95% *CI*: 3.5-9.6; respectively) than those with scores at or above the determined cut points. However, these *OR*s were attenuated, but were still statistically significant when adjusting for cardiorespiratory fitness status, for both relative HG (*OR*: 5.2, 95% *CI*: 2.4-11.5 for MetS; and *OR*: 7.3, 95% *CI*: 4.2-12.7 for cardiometabolic risk index) and absolute SLJ (*OR*: 3.6 95% *CI*: 1.7-7.7 for MetS; and *OR*: 4.7, 95% *CI*: 2.8-7.9 for cardiometabolic risk index).

4. Discussion

The aim of the present study was to determine whether HG and/or SLJ are capable of detecting risk of MetS in European adolescents, and to identify age- and sex-specific cut points for these tests. The main findings were that (1) the prevalence of MetS and elevated cardiometabolic risk index was 3.1 and 7.2% in European adolescents from 9 countries, respectively; (2) relative HG and absolute SLJ were the best muscle strength tests for detecting MetS and elevated cardiometabolic risk; (3) the identified muscle strength for detecting MetS and elevated cardiometabolic risk index were identical, which further reinforce the existence of a muscle threshold associated with cardiovascular health in youth; (4) age- and sex-specific health-related cut points were provided for European adolescents in order identify MetS and elevated cardiometabolic risk, which seems to be more discriminative for boys than for girls. This is the first study that establishes age- and sex-related health-related upper and lower muscle strength in adolescents.

The prevalence of MetS in children and adolescents varied between 0% and 60%, depending on the definition of MetS and the population examined.[23] For the pediatric population, there is a lack of a uniform definition. Many different MetS criteria have been applied in adolescents, and the components and cut points used to diagnose the MetS have varied considerably among studies.[18, 24] Several studies have used modified criteria based on the same concept in adults, according to Program/Adult Treatment Panel III[25] and the International Diabetes Federation.[1] These definitions are based on dichotomization of the cardiometabolic risk factors, and to be clinically diagnosed with MetS at least three cardiometabolic risk factors must be achieved, including obesity. However, other studies have established clustering of cardiometabolic risk factors, using continuous scores. Recently, Andersen et al.[24] showed that more children and adolescents had clustering of cardiometabolic risk factors (6.2% had 4 or more cardiometabolic risk factors) than the number fulfilling the International Diabetes Federation definition of MetS (less than 1%) for children and adolescents. In the present study, we included both methods, MetS and cardiometabolic risk index. For the dichotomous method, we used the model developed by Joliffe and Janssen,[18] who created age-specific cut points and MetS criteria for adolescents that were linked to the health-based Program/Adult Treatment Panel III and International Diabetes Federation adult criteria. For the continuous method, we chose the valid model by Martínez-Vizcaino et al.[19] who used confirmatory factor analysis comparing with other continuous methods. We observed that 3.1% had MetS and 7.2% European adolescents had elevated cardiometabolic risk index, which concurs with the figures reported by Andersen et al.[24]

The present study examined whether either HG or SLJ tests were capable of detecting elevated MetS and elevated cardiometabolic risk index in European adolescents. We selected the relative HG and absolute SLJ because the *AUC* value was higher for relative HG than for absolute HG. Moreover, although there was no difference in the *AUC* values between absolute and relative SLJ, the other discriminatory parameters showed that absolute SLJ identified thresholds to diagnose MetS and elevated cardiometabolic risk more accurately. Moreover, we excluded absolute HG and relative SLJ thresholds from any further analyses because we found positive associations with MetS and elevated cardiometabolic risk. If implemented (as part of a fitness testing program), adolescents with higher absolute HG or higher relative SLJ scores would actually be grouped in the ‘unhealthy zones’. It must be noted that heavier individuals have higher levels of absolute HG and relative SLJ, and the prevalence of MetS is higher in obese as opposed to normal weight children and adolescents, increasing with severity of obesity.[26] In addition, regarding the validity of the muscle strength tests, it is assumed that only non-weight-bearing fitness tests should be normalized by body mas.[27]

We reported age- and sex-specific relative HG and absolute SLJ cut points selected as the most accurate to detect MetS, and elevated cardiometabolic risk index in a relatively large sample of European adolescents. Ramirez-Velez et al.[28] developed age group-sex-specific cut points of relative HG for optimal cardiometabolic risk categorization in children (9-12.9 years old) and adolescents (13-17.9 years old) from Bogota (Colombia). In adolescent boys, the cut point reported by Ramirez-Velez et al. (0.447 kg/body mass) was similar to the one we established for 13-year-old adolescent boys. However, in girls, the cut point reported by Ramirez-Velez et al. (0.440 kg/body mass) was slightly higher than the ones we calculated for our European girls. Moreover, Peterson et al.[29] reported a high-risk cardiometabolic threshold for boys (≤ 0.33 kg/body mass) and girls (≤ 0.28 kg/body mass), an intermediate threshold (boys, > 0.33 and ≤ 0.45 kg/body mass; girls, > 0.28 and ≤ 0.36 kg/body mass), as well as a low-risk threshold for boys (> 0.45 kg/body mass) and girls (> 0.36 kg/body mass) in American adolescents. It is important to note that although the dichotomous (MetS) and continuous method (cardiometabolic risk index) used in this study showed different prevalence, both methods developed identical muscle strength cut points in the diagnosis. Moreover, these age- and sex-specific health-related cut points represented the percentile 25th and the 20th for relative HG and absolute SLJ. Boys and girls with relative HG or/and absolute SLJ scores below these percentiles had greater odds for MetS and elevated cardiometabolic risk index compared with those reaching the adequate percentiles, independently of cardiorespiratory fitness status. This finding reinforces the idea that an increased cardiometabolic risk is associated with the lowest quartile-quintile of muscle strength in adolescents.[30]

The Assessing Levels of PHysical Activity study developed a valid, reliable, feasible, and safe health-related fitness test battery for children and adolescents.[7] This study included, besides the HG test, the SLJ test to assess skeletal muscle strength. It is also important to highlight that both the HG and SLJ tests are the most used to assess muscle strength in children and adolescents. In fact, these tests are included in a number of field-based fitness test batteries.[10]

The observations of the present study are limited by the cross-sectional design nature, and causality cannot be determined. Also, there is a lack of consensus in youth regarding the definition of MetS. We decided to include both dichotomous and continuous methods so that the health-related cut points developed were the most accurate, regardless of the chosen method. Using one method or another could bias the results of the study, given the limitations of each method. However, in the present study, the resulting health-related cut points were the same for each model. Advantages of this study are the proper statistical analysis used (i.e. LMS method and ROC analysis) and the relative large sample of European adolescents, which allow providing age- and sex-specific health-related cut points of upper and lower body muscle strength. It should be noted that although ROC analyses are often used to create diagnostic tests, the first aim of the current study was to identify thresholds that demarcate inadequate/adequate strength relative to cardiometabolic risk factors rather than suggest that strength tests can be used to 'diagnose' MetS.

5. Conclusions

Relative HG and absolute SLJ were the best tests for detecting MetS in European adolescents. Moreover, relative HG appears to be a slightly better test than absolute SLJ to this end. Age- and sex-specific health-related cut points of upper and lower body muscle strength are provided for

European adolescents, which were still predictive of cardiometabolic risk after adjusting for cardiorespiratory fitness. These health-related cut points could be used as a starting point to define adequate levels of upper and lower muscle strength, and the diagnostic statistics provided herein can be used to offer feedback to adolescents, parents, and education and health professionals about what it means to meet or fail the test standards.

6. Practical implications

- The present study identifies age- and sex-related health-related upper and lower muscle strength associated with risk of metabolic syndrome in European adolescents.
- Risk of metabolic syndrome is associated with the lowest quartile-quintile of muscle strength in adolescents.
- These health-related cut points might be used as a screening tool to identify adolescents with risk of metabolic syndrome who may benefit from primary and secondary cardiovascular prevention programming.

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Table 1. ROC-derived cut points and diagnostic statistics for tests of muscle strength to determine elevated cardiometabolic risk index in boys and girls.

Test	Cut point Z-score	Cut point Percentile	Sensitivity (%)	Specificity (%)	Youden Index	PPV	NPV	DOR
Boys (n = 444)								
Handgrip (kg)	> 0.143	> 55.7	66.7	59.9	0.27	10.8	96.1	3.0
Rel. Handgrip (kg/mass kg)	≤ -0.728	≤ 23.3	80.0	79.7	0.60	22.2	98.2	15.8
Standing Long Jump (cm)	≤ -0.790	≤ 21.5	73.3	80.7	0.54	21.6	97.7	11.5
Rel. Standing Long Jump (cm x mass kg)	> 0.156	> 56.2	70.0	62.1	0.32	11.8	96.6	3.9
Girls (n = 506)								
Handgrip (kg)	> -0.287	> 38.7	84.2	40.8	0.25	10.4	97.0	3.6
Rel. Handgrip (kg/mass kg)	≤ -0.672	≤ 25.1	65.8	78.0	0.44	19.5	96.6	6.8
Standing Long Jump (cm)	≤ -0.846	≤ 19.9	44.7	83.1	0.28	17.7	94.9	4.0
Rel. Standing Long Jump (cm x mass kg)	> 0.623	> 73.5	57.9	79.5	0.37	18.6	95.9	5.3
Boys and Girls (n = 950)								
Handgrip (kg)	> -0.227	> 41.0	79.4	44.1	0.24	9.9	96.5	3.0
Rel. Handgrip (kg/mass kg)	≤ -0.672	≤ 25.1	72.1	78.1	0.50	20.2	97.3	9.1
Standing Long Jump (cm)	≤ -0.790	≤ 21.5	58.8	80.5	0.39	18.9	96.2	5.9
Rel. Standing Long Jump (cm x mass kg)	> 0.623	> 73.5	54.4	79.0	0.33	16.7	95.7	4.7

Rel., relative (test expressed by body mass); PPV, positive predictive value; NPV, negative predictive value; DOR, diagnostic odds ratio.

Cardiometabolic Risk Index Status defined by mean of age- and sex-specific z-scores for waist, TG/HDL ratio (triglycerides /high-density lipoprotein cholesterol), fasting insulin, mean arterial pressure (≥ 1.0) proposed by Martinez-Vizcaino et al.[19]

Table 2. ROC-derived cut points and diagnostic statistics for tests of muscle strength to determine metabolic syndrome in boys and girls.

Test	Cut point Z-score	Cut point Percentile	Sensitivity (%)	Specificity (%)	Youden Index	PPV	NPV	DOR
Boys (n = 449)								
Handgrip (kg)	> -0.129	> 44.9	72.7	49.1	0.22	3.5	98.6	2.6
Rel. Handgrip (kg/mass kg)	≤ -1.127	≤ 13.0	72.7	87.7	0.60	12.9	99.2	19.0
Standing Long Jump	≤ -0.890	≤ 18.7	63.6	80.8	0.44	7.7	98.9	7.4
Rel. Standing Long Jump (cm x mass kg)	> 0.156	> 56.2	72.7	61.2	0.34	4.5	98.9	4.2
Girls (n = 520)								
Handgrip (kg)	--	--	--	--	--	--	--	--
Rel. Handgrip (kg/mass kg)	≤ -0.713	≤ 23.8	63.2	76.9	0.40	9.4	98.2	5.7
Standing Long Jump (cm)	≤ -0.797	≤ 21.3	57.9	78.7	0.37	9.3	98.0	5.0
Rel. Standing Long Jump (cm x mass kg)	> 0.627	> 73.5	68.4	78.4	0.47	10.7	98.5	7.9
Boys and Girls (n = 969)								
Handgrip (kg)	> -0.834	> 20.2	96.7	23.2	0.20	3.9	99.5	9.0
Rel. Handgrip (kg/mass kg)	≤ -0.622	≤ 26.7	70.0	73.7	0.44	7.8	98.7	6.5
Standing Long Jump (cm)	≤ -0.797	≤ 21.3	60.0	78.6	0.39	8.2	98.4	5.5
Rel. Standing Long Jump (cm x mass kg)	> 0.627	> 73.5	56.7	77.9	0.35	7.6	98.3	4.6

Rel., relative (test expressed by body mass); PPV, positive predictive value; NPV, negative predictive value; DOR, diagnostic odds ratio.

Metabolic Syndrome Status defined by Jolliffe and Janssen.[24]

Table 3. Recommended age- and sex-specific cut points to detect elevated cardiometabolic risk index and metabolic syndrome using upper and lower body muscle strength tests.

Test	Relative Grip Strength (kg/kg mass)		Standing Long Jump (cm)	
Age/Sex	Boys	Girls	Boys	Girls
13 years old	0.44	0.41	135.4	118.1
14 years old	0.48	0.41	151.5	121.8
15 years old	0.52	0.41	165.4	123.0
16 years old	0.56	0.42	175.9	126.0
17 years old	0.59	0.42	184.2	129.5
Z-score	≤ -0.675		≤ -0.842	
Percentile	≤ 25.0		≤ 20.0	

Youth at or below the values would be considered as having 'poor' muscle strength based on the relevant test.
13 years old = 12.5 to 13.49 years old, 14 years old = 13.5 to 14.49 years old, etc.

Table S1. Descriptive characteristics of the adolescents participating in the study

Variable	Boys (n = 444)	Girls (n = 506)	Total (n = 950)
Age (years)	14.7 (1.2)	14.7 (1.2)	14.7 (1.2)
Stature (cm)	169.3 (9.8)*	161.7 (7.1)	165.3 (9.3)
Body Mass (kg)	61.3 (13.7)*	55.6 (10.2)	58.3 (12.3)
Overweight/Obese (%)	23.9%*	18.4%	20.9%
Healthy Cardiorespiratory Fitness (%)	51.5%*	38.9%	44.6%
Handgrip Strength (kg)[A]	35.6 (9.5)*	25.8 (4.9)	30.4 (8.9)
Rel. Handgrip Strength (kg/mass kg)	0.59 (0.12)*	0.47 (0.09)	0.53 (0.12)
Standing Long Jump (cm)	182.8 (32.6)*	144.2 (25.4)	162.3 (34.8)
Rel. Standing Long Jump (cm x mass kg)	11,226 (3,227)*	7,968 (1,783)	9,491 (3,033)
Waist Circumference (cm)	74.2 (9.1)*	70.4 (7.9)	72.2 (8.7)
Systolic Blood Pressure (mmHg)	123.9 (14.0)*	115.9 (11.4)	119.7 (13.3)
Diastolic Blood Pressure (mmHg)	67.3 (8.8)*	68.4 (8.7)	67.9 (8.8)
Mean Arterial Pressure (mmHg)	86.1 (9.3)*	84.2 (8.7)	85.1 (9.0)
Triglycerides (mg/dL)	63.1 (30.8)*	72.9 (37.6)	68.3 (34.9)
HDL-Cholesterol (mg/dL)	53.1 (10.0)*	57.3 (10.9)	55.3 (10.7)
TG/HDL Ratio (mg/dL)	1.28 (0.82)	1.36 (0.93)	1.32 (0.88)
Fasting Glucose (mg/dL)	92.9 (7.3)*	89.6 (6.7)	91.2 (7.2)
Fasting Insulin (µIU/mL)	10.2 (9.2)	10.4 (6.8)	10.3 (8.0)
Cardiometabolic Risk Index[B]	-0.03 (0.67)	-0.01 (0.63)	-0.01 (0.65)
Elevated Cardiometabolic Risk Index[C]	6.8%	7.5%	7.2%
Metabolic Syndrome prevalence[D]	2.4%	3.7%	3.1%

Values are Mean (SD), except percentages in the case of Overweight/Obese, Healthy CRF, cardiorespiratory fitness; and Metabolic Syndrome. Rel., relative; TG/HDL, triglyceride-to-high density

lipoprotein-cholesterol ratio.
*Statistically different from girls ($p < 0.05$).
[A]Average of right and left hands. [B]Mean of age- and sex-specific z-scores for waist, TG/HDL ratio, fasting insulin, mean arterial pressure. [C]Cardiometabolic Risk Index ≥ 1.0, based on Martinez-Vizcaino.[19] [D]Metabolic Syndrome based on Jolliffe and Janssen.[24]

Table S2. Pairwise comparisons of ROC area under the curve using muscle strength tests to detect elevated cardiometabolic risk index and metabolic syndrome in boys and girls.

Muscle Strength Parameter	Elevated Cardiometabolic Risk Index		Metabolic Syndrome	
	AUC (95% CI)	Significantly different AUC*	AUC (95% CI)	Significantly different AUC*
Boys	*n = 444*		*n = 449*	
A) Handgrip	0.655 (0.609, 0.700)	B, C	0.564 (0.517, 0.610)	B, C, D
B) Relative Handgrip	0.832 (0.793, 0.865)	A, D	0.873 (0.838, 0.902)	A, D
C) Standing Long Jump	0.775 (0.733, 0.813)	A	0.749 (0.706, 0.788)	A
D) Relative Standing Long Jump	0.702 (0.657, 0.744)	B	0.720 (0.675, 0.761)	A, B
Girls	*n = 506*		*n = 520*	
A) Handgrip	0.640 (0.592, 0.681)	B	0.539 (0.495, 0.582)	B, D
B) Relative Handgrip	0.748 (0.708, 0.785)	A	0.755 (0.716, 0.792)	A
C) Standing Long Jump	0.688 (0.645, 0.728)	--	0.622 (0.620, 0.703)	--
D) Relative Standing Long Jump	0.697 (0.655, 0.737)	--	0.676 (0.634, 0.716)	A
Boys and Girls	*n = 950*		*n = 969*	
A) Handgrip	0.647 (0.615, 0.677)	B, C	0.549 (0.517, 0.581)	B, C, D
B) Relative Handgrip	0.786 (0.758, 0.812)	A	0.799 (0.773, 0.824)	A, C
C) Standing Long Jump	0.728 (0.698, 0.756)	A	0.695 (0.665, 0.724)	A, B
D) Relative Standing Long Jump	0.699 (0.668, 0.728)	--	0.693 (0.662, 0.721)	A

AUC = Area under the receiver operating characteristic (ROC) curve where muscle strength parameter was used to detect presence/absence of metabolic risk/syndrome.

*AUC significantly different from correspondingly labeled test within column based on Hanley and McNeil [30], $p < 0.05$.

Cardiometabolic Risk Index defined by mean of age- and sex-specific z-scores for waist, TG/HDL ratio, insulin, mean arterial pressure (≥ 1.0) proposed by Martinez-Vizcaino et al. [19]

Metabolic Syndrome defined by Jolliffe and Janssen.[24]

Table S3. Logistic regression of elevated cardiometabolic risk index and metabolic syndrome by muscle strength tests.

Model	Relative Grip Strength		Standing Long Jump	
	Cardiometabolic Risk Index	Metabolic Syndrome	Cardiometabolic Risk Index	Metabolic Syndrome
	n = 961	*n = 980*	*n = 954*	*n = 973*
Model 1				
Unadjusted	8.5 (5.0, 14.7)	6.2 (2.9, 13.4)	5.8 (3.5, 9.6)	4.5 (2.3, 9.4)
Model 2				
Adjusted for aerobic fitness status	7.3 (4.2, 12.7)	5.2 (2.4, 11.5)	4.7 (2.8, 7.9)	3.6 (1.7, 7.7)

Values are odds ratio and 95% confidence interval (OR, 95% CI), the meeting recommended muscle strength group was referent (OR = 1.0).