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Word count: 3578

Abstract word count: 233

Number of Table: 3

1   **ABSTRACT**

2   **Objectives:** To determine whether handgrip strength (HG) and/or standing long jump (SLJ) are

3   capable of detecting risk of metabolic syndrome (MetS) in European adolescents, and to identify

4   age- and sex-specific cut points for these tests.

5   **Design:** Cross-sectional study.

6   **Methods:** Participants included 969 (aged 12.5-17.5 years old) adolescents from 9 European

7   countries (n=520 girls). Absolute and relative HG and SLJ tests were used to assess upper and

8   lower muscle strength, respectively. MetS status was determined using the age- and sex-specific

9   cut points proposed by Jolliffe and Janssen´s, Additionally, we computed a continuous

10   cardiometabolic risk index with the average z-score of four cardiometabolic risk factors: Wait

11   circumference, mean arterial pressure, triglycerides/high-density lipoprotein cholesterol, and

12   fasting insulin.

13   **Results:** The prevalence of MetS was 3.1% in European adolescents. Relative HG and absolute

14   SLJ were the best tests for detecting the presence of MetS (Area under the receiver operating

15   characteristic (AUC)=0.799, $95\%CI$:0.773-0.824; and AUC=0.695 $95\%CI$:0.665-0.724),

16   respectively) and elevated cardiometabolic risk index (AUC=0.873, $95\%CI$:0.838-0.902; and

17   AUC=0.728 $95\%CI$:0.698-0.756), respectively) and, regardless of cardiorespiratory fitness. We

18   provide age- and sex-specific cut points of upper and lower muscle strength for European

19   adolescents to identify the presence of MetS and elevated cardiometabolic risk index.

20   **Conclusions:** The proposed health-related cut points could be used as a starting point to define

21   health-related levels of upper and lower muscle strength in adolescents. Likewise, the diagnostic

22   statistics provided herein can be used to offer feedback to adolescents, parents, and education

23   and health professionals about what it means to meet or fail test standards.

24   **Key words:** <mark>Muscle fitness</mark>. Cardiometabolic risk. Adolescents

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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

70 jump (SLJ) tests. <mark>Both tests have been proposed to assess upper and lower body muscle strength</mark>

71 <mark>levels in European youth.</mark>[7] In addition, the HELENA study also collected data on MetS and other

72 relevant clinical and socio-demographic features in a large sample of European adolescents, <mark>thus</mark>

73 <mark>providing a great opportunity (i) to determine whether the HG and/or SLJ tests are capable of</mark>

74 <mark>detecting risk of MetS in European adolescents, and (ii) to identify age- and sex-specific cut</mark>

75 <mark>points for these tests.</mark>

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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,

111 Hamburg, Germany). BMI was calculated as body mass (kg) / stature $(m)^2$. The International

112 Obesity Task Force BMI standards were used to categorize children as normal weight or

113 overweight/obese.[9]

Physical Fitness

115 Upper and lower body muscle strength levels were measured by the HG and the SLJ tests,[7]

116 respectively. Both test are valid[10], reliable[11], feasible and safe[12] to be used both at population

117 level and in the school-setting.[7] A hand dynamometer with an adjustable grip (TKK 5101 Grip

118 D, Takey, Tokyo, Japan) was used for the HG test. The adolescent squeezed the dynamometer

119 continuously for at least 2 seconds, alternatively with right and left hands, with the elbow in full

120 extension. The grip-span of the dynamometer was adjusted according to the hand size of the

121 adolescent. The test was performed twice, allowing a 1-minute rest between the measurements to

122 avoid local muscle fatigue, and the maximum score for each hand was recorded in kilograms as

123 described elsewhere.[13] The average of the scores achieved by the left and right hands was used in

124 the analyses to have an overall measure of the handgrip strength.[13] The SLJ was performed from

125 a starting position immediately behind a line, standing with feet approximately shoulder's width

126 apart, and the adolescent jumped as far forward as possible, landing with their feet together. The

127 test was performed twice, with 1-minute rest between the measurements, and the longest distance

128 achieved was recorded in centimeters. Before conducting the tests, adolescents had a

129 familiarization trial. Nevertheless, as these tests are commonly used in the school setting to

130 measure fitness performance, adolescents were rather familiarized. We converted HG and SLJ to

131 relative scores by expressing HG as strength divided by body mass [strength (kg) / body mass

132 (kg)] and expressing SLJ as jump distance multiplied by body mass [jump distance (cm) x body

133 mass (kg)].

134 In order to determine the potential influence of cardiorespiratory fitness (a well-known important

135 marker of health in adolescents[3] on the association of HG and/or SLJ with the risk of MetS, we

136 decided to control the analysis by this variable. We assessed cardiorespiratory fitness by the 20

137 m shuttle run test and the maximum oxygen consumption (VO_{2max}, ml/kg/min) by the equation

138 reported by Léger et al.[14] Each adolescent was grouped into a cardiorespiratory fitness status

139 (low or high) according to the FITNESSGRAM standards Healthy Fitness Zone as follows: low

140 corresponds to the "needs improvement" category, and high correspond to the "healthy fitness

141 zone".[15] All these fitness tests have shown to be valid and reliable in children and adolescents.[10,

142 11]

143 *Cardiometabolic risk factors*

144 Waist circumference was measured in triplicate using an anthropometric tape (SECA 200) as the

145 midpoint between the lowest rib and the iliac crest.[16] Diastolic and systolic blood pressure were

146 measured after being seated in a quiet room for 10 min with their back supported and feet on the

147 ground. Two diastolic and systolic blood pressure readings were taken with a 10-min interval of

148 quiet rest. The lower value of the two measurements was used in the analysis. We calculated the

149 mean arterial pressure as [diastolic blood pressure + (0.333 x (systolic blood pressure - diastolic

150 blood pressure))]. A detailed description of the blood samples' analysis has been reported

151 elsewhere.[17] Venous blood was obtained by venipuncture after an overnight fast. Serum TG,

152 HDL, and fasting glucose were measured on a Dimension RxL clinical chemistry system (Dade

153 Behring, Schwalbach, Germany) using enzymatic methods. Fasting insulin concentrations were

154 measured by a solid-phase two-site chemiluminescent immunometric assay, using an Immulite

155 2000 analyzer (DPC Biermann GmbH, Bad Nauheim, Germany).

156   MetS status was also determined using WC, diastolic and systolic blood pressure, TG,

157   HDL, and fasting glucose with the definition by Jolliffe and Janssen reported in 2007.[18] This

158   pediatric definition was created using growth curves to back-extrapolate the National Cholesterol

159   Education Program/Adult Treatment Panel II adult values for adolescents. The participants were

160   considered as having an individual elevated cardiometabolic risk factor if they had a high WC,

161   either systolic or diastolic blood pressure, TG, HDL, or fasting glucose. Adolescents with 3 or

162   more elevated cardiometabolic risk factors were considered as having MetS.

163   Additionally, all cardiometabolic risk factors were expressed as age- and sex-specific z-

164   scores based on the current sample to account for changes during growth and maturation.

165   Further, a continuous cardiometabolic risk index was computed as the average z-score of four

166   cardiometabolic risk factors (WC, mean arterial pressure, TG/HDL ratio, and fasting insulin).

167   The adolescents were categorized as having elevated cardiometabolic risk if their

168   cardiometabolic risk index was one standard deviation above the mean for each of the four

169   markers. This cardiometabolic risk index methodology has been previously validated in children

170   and adolescents.[19]

171   The descriptive data are shown as mean and standard deviation unless otherwise

172   indicated, and the sexes were compared with independent samples t-tests and chi-square tests of

173   independence. Receiver operating characteristic (ROC) analyses were completed for all four

174   muscle strength parameters: absolute HG, relative HG (HG / body mass), absolute SLJ, and

175   relative SLJ (SLJ x body mass). The Least Mean Square (LMS) method[20] was used to create age-

176   and sex-specific z-scores and were used in the main analysis.

177   In the current study, we constructed ROC curves to detect MetS and elevated

178   cardiometabolic risk index from the four muscle strength parameters. The resulting ROC curves

179 and data provide several key variables that aid in identifying appropriate thresholds, such as: area

180 under the ROC curve (*AUC*), sensitivity, specificity, Youden Index (i.e. the sum of sensitivity

181 and specificity minus one, and is the most commonly used indicator of an ideal cut point on the

182 ROC curve), positive predictive value (*PPV*), negative predictive value (*NPV*), and the

183 diagnostic odds ratio (*OR*).[21] In terms of this analysis, *AUC* is a test of global discriminatory

184 accuracy indicating how well the muscle strength z-score can differentiate between MetS vs. no-

185 MetS and elevated vs. low cardiometabolic risk index.

186   The ROC curves were initially constructed separately by sex, and then for the total

187 sample to identify the impact of combining both sexes. After creating the curves, the four tests of

188 muscle strength were compared to identify the best tests/metrics to use for the intended purpose:

189 whether absolute or relative HG, and absolute or relative SLJ. Pairwise comparisons of the *AUC*

190 values were made using the methods outlined by Hanley and McNeil.[22] Then, to select the ideal

191 cut points for each of the four tests, we primarily made decisions based on the Youden Index, but

192 we also gave consideration to the *PPV, NPV*, and diagnostic *OR* for each threshold. After

193 selecting the ideal cut points, to determine how the predictive utility of the thresholds would be

194 impacted by cardiorespiratory fitness, we used logistic regression to estimate the odds of MetS

195 and elevated cardiometabolic risk index in youth with muscle strength cut points (low vs. high

196 levels) in two models: unadjusted or adjusted for cardiorespiratory fitness status. The LMS

197 percentile curves and ROC curves were constructed using LMS ChartMaker Pro (version 2.3).

198 All other analyses were done using IBM SPSS (version 20.0). The alpha level for all analyses

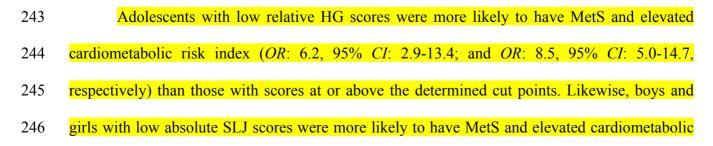199 was set at $p \leq 0.05$.

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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 49th percentile). However, the 5th highest Youden Index (z-score = -0.846) had a higher specificity,

224 *PPV*, and diagnostic *OR*. Because it afforded these advantages and was still within the top 1% of

225 Youden Index scores it was selected instead.

226 **Table 2** depicts the selected thresholds for each muscle strength test to identify MetS.

227 Each 'ideal' cut point had the highest Youden Index available except two boys' thresholds,

228 relative HG and absolute SLJ. For both, the cut point with the highest Youden Index was

229 relatively unbalanced, a very low specificity for relative HG (z-score = -0.4847) and a high

230 specificity for absolute SLJ (z-score = -1.5557). The relative HG and absolute SLJ cut points

231 selected for boys where those with the higher sensitivities, specificities, *PPV*, *NPV*, and odds

232 ratios (z-score = -1.127 and -0.890, respectively). Moreover, Youden Index scores were near the

233 top of the possible cut points. The diagnostic *OR*s were higher for boys than girls. It should be

234 noted that the cut points for absolute HG and relative SLJ are reversed from what would be

235 considered intuitive. Higher absolute HG and relative SLJ scores were more indicative of greater

236 odds of having MetS or an elevated cardiometabolic risk index.

237 **Table 3** outlines the selected age- and sex-specific scores for relative HG and absolute

238 SLJ for boys and girls derived in the current study. These approximate the 25th and 20th

239 percentiles using the LMS parameters for relative HG and absolute SLJ, respectively. These final

240 cut points are based on the 'ideal' cut points for boys and girls from Tables 2 and 3, where the

241 relative HG cut points for boys and girls were the 25.1th and 26.7th percentiles, and the absolute

242 SLJ cut points were the 21.5th and 21.3rd.

243 Adolescents with low relative HG scores were more likely to have MetS and elevated

244 cardiometabolic risk index (*OR*: 6.2, 95% *CI*: 2.9-13.4; and *OR*: 8.5, 95% *CI*: 5.0-14.7,

245 respectively) than those with scores at or above the determined cut points. Likewise, boys and

246 girls with low absolute SLJ scores were more likely to have MetS and elevated cardiometabolic

247 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

248 scores at or above the determined cut points. However, these *OR*s were attenuated, but were still

249 statistically significant when adjusting for cardiorespiratory fitness status, for both relative HG

250 (*OR*: 5.2, 95% *CI*: 2.4-11.5 for MetS; and *OR*: 7.3, 95% *CI*: 4.2-12.7 for cardiometabolic risk

251 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

252 cardiometabolic risk index).

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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

290 more children and adolescents had clustering of cardiometabolic risk factors (6.2% had 4 or

291 more cardiometabolic risk factors) than the number fulfilling the International Diabetes

292 Federation definition of MetS (less than 1%) for children and adolescents. In the present study,

293 we included both methods, MetS and cardiometabolic risk index. For the dichotomous method,

294 we used the model developed by Joliffe and Janssen,[18] who created age-specific cut points and

295 MetS criteria for adolescents that were linked to the health-based Program/Adult Treatment

296 Panel III and International Diabetes Federation adult criteria. For the continuous method, we

297 chose the valid model by Martínez-Vizcaino et al.[19] who used confirmatory factor analysis

298 comparing with other continuous methods. We observed that 3.1% had MetS and 7.2% European

299 adolescents had elevated cardiometabolic risk index, which concurs with the figures reported by

300 Andersen et al.[24]

301   The present study examined whether either HG or SLJ tests were capable of detecting

302 elevated MetS and elevated cardiometabolic risk index in European adolescents. We selected the

303 relative HG and absolute SLJ because the *AUC* value was higher for relative HG than for

304 absolute HG. Moreover, although there was no difference in the *AUC* values between absolute

305 and relative SLJ, the other discriminatory parameters showed that absolute SLJ identified

306 thresholds to diagnose MetS and elevated cardiometabolic risk more accurately. Moreover, we

307 excluded absolute HG and relative SLJ thresholds from any further analyses because we found

308 positive associations with MetS and elevated cardiometabolic risk. If implemented (as part of a

309 fitness testing program), adolescents with higher absolute HG or higher relative SLJ scores

310 would actually be grouped in the 'unhealthy zones'. It must be noted that heavier individuals

311 have higher levels of absolute HG and relative SLJ, and the prevalence of MetS is higher in

312 obese as opposed to normal weight children and adolescents, increasing with severity of

313   obesity.[26] In addition, regarding the validity of the muscle strength tests, it is assumed that only

314   non-weight-bearing fitness tests should be normalized by body mas.[27]

315   We reported age- and sex-specific relative HG and absolute SLJ cut points selected as the

316   most accurate to detect MetS, and elevated cardiometabolic risk index in a relatively large

317   sample of European adolescents. Ramirez-Velez et al.[28] developed age group-sex-specific cut

318   points of relative HG for optimal cardiometabolic risk categorization in children (9-12.9 years

319   old) and adolescents (13-17.9 years old) from Bogota (Colombia). In adolescent boys, the cut

320   point reported by Ramirez-Velez et al. (0.447 kg/body mass) was similar to the one we

321   established for 13-year-old adolescent boys. However, in girls, the cut point reported by

322   Ramirez-Velez et al. (0.440 kg/body mass) was slightly higher than the ones we calculated for

323   our European girls. Moreover, Peterson et al.[29] reported a high-risk cardiometabolic threshold for

324   boys ($\leq$ 0.33 kg/body mass) and girls ($\leq$ 0.28 kg/body mass), an intermediate threshold (boys, >

325   0.33 and $\leq$ 0.45 kg/body mass; girls, > 0.28 and $\leq$ 0.36 kg/body mass), as well as a low-risk

326   threshold for boys (> 0.45 kg/body mass) and girls (> 0.36 kg/body mass) in American

327   adolescents. It is important to note that although the dichotomous (MetS) and continuous method

328   (cardiometabolic risk index) used in this study showed different prevalence, both methods

329   developed identical muscle strength cut points in the diagnosis. Moreover, these age- and sex-

330   specific health-related cut points represented the percentile 25th and the 20th for relative HG and

331   absolute SLJ. Boys and girls with relative HG or/and absolute SLJ scores below these percentiles

332   had greater odds for MetS and elevated cardiometabolic risk index compared with those reaching

333   the adequate percentiles, independently of cardiorespiratory fitness status. This finding reinforces

334   the idea that an increased cardiometabolic risk is associated with the lowest quartile-quintile of

335   muscle strength in adolescents.[30]

336   The Assessing Levels of PHysical Activity study developed a valid, reliable, feasible, and

337   safe health-related fitness test battery for children and adolescents.[7] This study included, besides

338   the HG test, the SLJ test to assess skeletal muscle strength. It is also important to highlight that

339   both the HG and SLJ tests are the most used to assess muscle strength in children and

340   adolescents. In fact, these tests are included in a number of field-based fitness test batteries.[10]

341   The observations of the present study are limited by the cross-sectional design nature, and

342   causality cannot be determined. Also, there is a lack of consensus in youth regarding the

343   definition of MetS. We decided to include both dichotomous and continuous methods so that the

344   health-related cut points developed were the most accurate, regardless of the chosen method.

345   Using one method or another could bias the results of the study, given the limitations of each

346   method. However, in the present study, the resulting health-related cut points were the same for

347   each model. Advantages of this study are the proper statistical analysis used (i.e. LMS method

348   and ROC analysis) and the relative large sample of European adolescents, which allow providing

349   age- and sex-specific health-related cut points of upper and lower body muscle strength. It

350   should be noted that although ROC analyses are often used to create diagnostic tests, the first

351   aim of the current study was to identify thresholds that demarcate inadequate/adequate strength

352   relative to cardiometabolic risk factors rather than suggest that strength tests can be used to

353   'diagnose' MetS.

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355   **5. Conclusions**

356   Relative HG and absolute SLJ were the best tests for detecting MetS in European adolescents.

357   Moreover, relative HG appears to be a slightly better test than absolute SLJ to this end. Age- and

358   sex-specific health-related cut points of upper and lower body muscle strength are provided for

359   European adolescents, which were still predictive of cardiometabolic risk after adjusting for

360   ==cardiorespiratory fitness==. These health-related cut points could be used as a starting point to

361   define adequate levels of upper and lower muscle strength, and the diagnostic statistics provided

362   herein can be used to offer feedback to adolescents, parents, and education and health

363   professionals about what it means to meet or fail the test standards.

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365 **6. Practical implications**

366 • The present study identifies age- and sex-related health-related upper and lower muscle

367 strength associated with risk of metabolic syndrome in European adolescents.

368 • Risk of metabolic syndrome is associated with the lowest quartile-quintile of muscle

369 strength in adolescents.

370 • These health-related cut points might be used as a screening tool to identify

371 adolescents with risk of metabolic syndrome who may benefit from primary and

372 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]

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 ($\geq$ 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).