Strength Capacity and Cardiometabolic Risk Clustering in Adolescents

WHAT’S KNOWN ON THIS SUBJECT: Resistance exercise is known to have a robust effect on glycemic control and cardiometabolic health among children and adolescents, even in the absence of weight loss.

WHAT THIS STUDY ADDS: Normalized strength capacity is associated with lower cardiometabolic risk clustering in boys and girls, even after adjustment for cardiorespiratory fitness, level of physical activity, and BMI.

abstract

OBJECTIVES: The purpose of this study was to determine the gender-specific independent association between muscular strength and cardiometabolic risk clustering in a large cohort (n = 1421) of children.

METHODS: Principal component analysis was used to determine the pattern of risk clustering and to derive a continuous aggregate score (MetScore) from various cardiometabolic risk components: percent body fat (%BF), fasting glucose, blood pressure, plasma triglycerides levels, and HDL-cholesterol. Gender-stratified risk and MetScore were assessed by using general linear models and logistic regression for differences between strength tertiles, as well as independent associations with age, BMI, estimated cardiorespiratory fitness (CRF), physical activity, and muscular strength (normalized for body mass).

RESULTS: In both boys (n = 670) and girls (n = 751), there were significant differences in cardiometabolic profiles across strength tertiles, such that stronger adolescents had lower overall risk. Age, BMI, cardiorespiratory fitness, physical activity participation, and strength were all individually correlated with multiple risk components, as well as the overall MetScore. However, in the adjusted model, only BMI (β = 0.30), physical inactivity (β = 0.30), and normalized strength capacity (β = −1.5) emerged as significant (P < .05) predictors of MetScore. %BF was the strongest loading coefficient within the principal component analysis–derived MetScore outcome.

CONCLUSIONS: Normalized strength is independently associated with lower cardiometabolic risk in boys and girls. Moreover, %BF was associated with all cardiometabolic risk factors and carried the strongest loading coefficient. These findings bolster the importance of early strength acquisition and healthy body composition in childhood. Pediatrics 2014;133:e896–e903

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KEY WORDS: muscle strength, children, cardiometabolic, principal component analysis

ABBREVIATIONS
CDC—Centers for Disease Control and Prevention
CHIP—Cardiovascular Health Intervention Program
CRF—cardiorespiratory fitness
FFM—fat-free mass
HDL—high-density lipoprotein
PA—physical activity
PCA—principal component analysis
%BF—percent body fat
RE—resistance exercise
SBP—systolic blood pressure
VO2 max—maximal oxygen consumption
WC—waist circumference

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Emerging evidence has demonstrated the importance of resistance exercise (RE) and strength preservation in the protection against cardiometabolic diseases and early all-cause mortality. Indeed, among adults with and without existing risk factors, numerous studies have reported significantly improved insulin sensitivity and glucose tolerance with structured RE interventions. There is also compelling evidence to support the efficacy of progressive RE for glycemic control among children and adolescents, even in the absence of weight loss. However, because RE is known to elicit a potent insulin-sensitizing effect for hours after a single bout of training, there is some speculation about whether it is merely the repeated acute responses to habitual RE that drive benefits for metabolic health, rather than any adaptive-response per se. Regardless, because childhood activity level appears to track into adulthood, RE may be a vital component of health-related physical activity for metabolic fitness in children and adolescents.

However, at present, little is known about the extent to which varying degrees of strength is associated with clinically relevant cardiometabolic clustering in children, especially after adjustment for other established explanatory variables. Such information would provide support for an intrinsic protective mechanism with greater muscular strength capacity and thus further reinforce the value of early RE, as well as simple muscular strength screening in pediatric populations.

We have recently demonstrated the efficacy of using principal components analysis (PCA) to construct a cardiometabolic risk score in adolescents. PCA can be effectively used in pediatric cohorts to aid the interpretation of statistical component clustering, as well as for identifying behavioral predictors of risk. Although previous studies have incorporated similar continuous scores to improve robustness of cardiometabolic risk assessment in pediatric research, the PCA method also calculates the respective "weight" (i.e., the loading coefficient) of each component on absolute cardiometabolic risk. Although the loading coefficients are limited to the specific data set from which they are derived, this strategy enables the aggregation of key metabolic syndrome risk components that are known to cluster and also provides a weighted, continuous metabolic syndrome risk outcome that is demonstrated to remain stable into young adulthood.

In using this strategy, statistical power is maximized, thus allowing for a more sensitive, robust assessment of cardiometabolic profiles. Although several previous studies have examined the contribution of muscular fitness on cardiometabolic profiles in children and adolescents, to date the PCA technique has yet to be used for identifying the independent association between normalized strength and cardiometabolic risk clustering in this population. The purpose of this investigation was therefore to use a PCA-derived continuous score and assess the independent influence of muscular strength capacity on gender-specific pediatric cardiometabolic risk, adjusting for established covariates such as age, BMI, physical activity (PA) level, and cardiovascular fitness (CRF).

**METHODS**

**Study Overview**

The Cardiovascular Health Intervention Program (CHIP) is a population-based study of sixth-graders that includes a screening component and health education program. Details of the program have been described in detail. Briefly, screenings include the following cardiometabolic risk factor assessments: PA, estimated CRF, body composition, blood pressure, family history, fasted blood lipids, fasted glucose, grip strength, and a blood spot sample for genotyping. Of the data collected, we incorporated traditional metabolic syndrome components (fasting glucose, systolic blood pressure, triglycerides, etc), as well as percent body fat (%BF), for aggregating the outcome of cardiometabolic risk, and numerous predictor variables (cardiorespiratory fitness, BMI, waist circumference [WC]) based on preliminary bivariate analyses and previous/current literature. Equal recruitment of boys (51%) and girls (49%) into the program permits a formal assessment of gender-specific characteristics in cardiometabolic risk.

**Participants**

Between 2005 and 2008, sixth-grade students from 17 mid-area Michigan schools were recruited to participate in CHIP. Among the 4159 children who completed assent and consent forms, 3970 children underwent a complete health risk assessment. The following participants were excluded from the study: (1) 87 children reported to have heart problems, (2) 14 reported to have diabetes, (3) 2 reported to have both heart problem and diabetes, (4) 10 had fasting blood glucose levels >126 mg/dL, and (5) 39 had incomplete measures on cardiometabolic risk components. Among the 3970 children who underwent a complete health risk assessment, 1421 sixth-grade students (52.9% female, 95% Caucasian, 10–13 years of age) were included in this analysis that had valid strength measures. The CHIP protocol was reviewed and approved by the institutional review board at Central Michigan University, as well as the administration of each participating school.

**Anthropometric and Body Composition Measures**

Height was measured to the nearest 0.5 cm using a stadiometer. Body mass...
was recorded to the nearest 0.5 kg using an electronic scale (BWB-800-Tanita, Tokyo Japan). WC was measured with a Gulick tape measure at a level midway between the lowest rib and the iliac crest. Hip circumference was measured at the maximal protuberance of the buttocks. Waist-to-hip ratio was calculated as WC (cm) divided by hip circumference (cm). BMI was calculated (kg • m⁻²), and obesity prevalence was estimated based on growth chart percentiles developed by the Centers for Disease Control and Prevention (CDC). Children with a BMI ≥85th and <95th percentile of age- and gender-specific reference population²⁵ were designated as overweight, and children with BMIs ≥95th percentile was considered obese.

Skinfolds thicknesses were measured by using Lange skinfold calipers (Beta Technology, Santa Cruz, CA) at the triceps and calf. Triceps adipose tissue was separated and measured at a point between the acromial process and elbow. The procedure was repeated at the calf, with the measure taken on the medial side of the right leg at the largest girth. Three measurements were taken at each site, and the mean score was used. %BF was estimated from the prediction equation by Lohman,²⁶ separately for males (%BF = [0.735 × sum of skinfolds] + 1.0), and females (%BF = [0.610 × sum of skinfolds] + 5.0). Additionally, a fat-free mass (FFM) index (FFMI) was also calculated as [FFM (kg) • height (m)⁻²], as previously described.²⁷

Blood Pressure and Serum Cardiometabolic Parameters

Systolic (SBP) and diastolic blood pressure were measured using a sphygmomanometer according to the standard American Heart Association protocol for children.²⁸⁻²⁹ The mean of the 2 measurements was calculated and used in the analysis. Fasting blood was obtained to measure a lipid profile and glucose levels. Children and parents were instructed to have the child fast for a minimum of 8 hours the night before the screening and refrain from eating breakfast the morning of the screening. Blood samples were analyzed by using a calibrated Cholestech LDX cholesterol analyzer (Cholestech Corporation, Hayward, CA). A complete glucose/lipid panel measurement included high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol, non-HDL cholesterol, total cholesterol, and triglycerides, and blood glucose.

Habitual PA

PA was assessed by questionnaire during the screening. The questionnaire was developed and validated by the CDC for the Youth Risk Behavior Surveillance System and has been used to measure progress toward achieving national health objectives.³⁰ Each student was interviewed about the number of days he or she was physically active during the previous 7 days. Being physically active was defined as accumulating a minimum of 60 minutes per day for ≥5 days per week, in any kind of PA that raised heart rate and breathing rate above the resting state. Children were categorized as either physically active or not active, based on whether they were physically active for ≥5 days or not.

CRF

A 7-minute step test (modified Canadian Home fitness test) was used to evaluate each child’s CRF level. Using a Polar heart rate monitor model 60911 (Polar Electro, Woodbury, NY), participants performed continuous stepping on a 20-cm set of steps for 7 minutes. A validated regression equation was used to estimate maximal oxygen consumption (VO₂).³¹ Cut points for a healthy level of aerobic capacity were ≥39 and 42 mL/kg/minute for girls and boys, respectively. The validity of this test was confirmed by conducting a treadmill VO₂ max test among a subset of children (n = 20; interclass correlation coefficient, r = 0.80, P < .01).

Grip Strength

Strength was assessed by using a hydraulic handgrip dynamometer (Jamar Technologies, Horsham, PA). Subjects sat with the shoulder adducted, the elbow flexed in a 90° angle, and the wrist in a neutral position. Three strength trials of the dominant hand were obtained, and the mean of the 3 tests was used. Because of the wide variability in body size among both boys and girls, as well as the robust association between body stature and strength in children and adolescents,³² handgrip strength was normalized per weight and height, as strength per body mass and strength per height ratios, respectively. Handgrip strength has been shown to be highly correlated with total muscle strength in children and adolescents³³ and has excellent criterion validity and reliability.³⁴ Moreover, the Institute of Medicine recently issued a report on fitness measures and health outcomes in youth with recommendations to include handgrip strength as a measure of musculoskeletal fitness.³⁵

Continuous Cardiometabolic Risk Score (MetScore)

Five cardiometabolic components (%BF, SBP, triglycerides, HDL, and glucose) were analyzed with PCA. Triglycerides levels were log-transformed to correct for skewed distribution. HDL was multiplied by −1 because it is reciprocally associated with cardiometabolic risk. Only SBP was used in the MetScore because SBP and diastolic blood pressure were highly correlated. Children with valid measurements in all 5 risk factors (n = 751 girls and 670 boys) were included in the PCA. PCA with varimax rotation was applied to the individual risk factors to derive components that represent large fractions of metabolic syndrome variance. In using
this method, higher MetScores were indicative of greater cardiometabolic risk.

**Statistical Analysis**

All statistical analyses were performed by using SAS software version 9.1 (SAS Institute, Cary, NC). Normal distribution of each cardiometabolic component measurement was checked by using a Shapiro-Wilk test in combination with graphical methods. Bivariate analyses between all the variables under study were tested by using a Pearson’s correlation. Descriptive characteristics were examined across strength tertiles and between genders and are provided as means, standard errors, and percentages. Differences in these characteristics across strength categories were tested by using linear regression and logistic regression for continuous and categorical variables respectively, after creating appropriate categories and dummy coding for each. Gender-stratified multiple regression analyses were conducted to test the independent associations of each individual cardiometabolic risk factors and potential predictors. Linearity between dependent variable and the explanatory variables were checked graphically. Homogeneity of the variance of the residuals was tested by White’s General Specification test, and multicollinearity was tested by using a variance inflation factor.

The association between MetScore and various explanatory variables were analyzed by using multiple regression analyses. In each model, MetScore was entered as the continuous dependent variable, and children’s PA participation, normalized strength, and CRF were entered as independent predictors, along with potential mediating factors (i.e., WC and BMI). The PCA analysis revealed 2 principal components with eigen values ≥1.0 in both girls and boys. The first principal component (PC1) was correlated with all metabolic syndrome components except glucose. The second principal component (PC2) was correlated with glucose, SBP, and HDL. PC1 and PC2 accounted for 57% and 60% of MetScore variance in females and males, respectively.

**RESULTS**

Descriptive characteristics are presented in Table 1, as means and SE differences between strength tertiles, as well as between boys and girls. From the total sample, 42.2% of children were overweight or obese (i.e., at or above the gender-specific 85th percentile on the CDC’s 2000 BMI-for-age growth charts). In both boys and girls, individuals in the highest tertiles for normalized strength (per body mass) had significantly lower BMIs, WCs, %BF, FFMI, CRF, and absolute fat mass, as well as significantly lower levels of clinical cardiometabolic parameters. There were no differences in self-reported PA participation between individuals in the lowest strength tertile (boys: 3.4 days; girls: 2.8 days; P > .05), as compared with individuals in the medium (boys: 3.5 days; girls: 2.9 days).

**TABLE 1 Characteristics of Participants by Strength Tertile and Gender**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys</th>
<th></th>
<th>Girls</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Strength</td>
<td>Moderate Strength</td>
<td>High Strength</td>
<td>Low Strength</td>
</tr>
<tr>
<td></td>
<td>(n = 244)</td>
<td>(n = 223)</td>
<td>(n = 203)</td>
<td>(n = 273)</td>
</tr>
<tr>
<td>Age, y</td>
<td>11.61 (0.04)</td>
<td>11.61 (0.04)</td>
<td>11.74 (0.04)</td>
<td>11.48 (0.03)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>155.08 (0.48)</td>
<td>152.58 (0.55)</td>
<td>152.29 (0.57)</td>
<td>154.29 (0.44)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.60 (0.93)</td>
<td>47.48 (0.78)</td>
<td>43.11 (0.61)</td>
<td>60.04 (0.94)</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>24.58 (0.31)</td>
<td>20.18 (0.22)</td>
<td>18.44 (0.17)</td>
<td>25.24 (0.32)</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>83.96 (0.91)</td>
<td>70.39 (0.67)</td>
<td>64.43 (0.51)</td>
<td>81.63 (0.63)</td>
</tr>
<tr>
<td>LDL cholesterol, mg/dL</td>
<td>104 (2.10)</td>
<td>101 (2.30)</td>
<td>94 (2.32)</td>
<td>99 (1.65)</td>
</tr>
<tr>
<td>HDL cholesterol, mg/dL</td>
<td>50 (0.97)</td>
<td>54 (1.05)</td>
<td>55 (1.01)</td>
<td>49 (0.86)</td>
</tr>
<tr>
<td>Total cholesterol, mg/dL</td>
<td>172 (2.23)</td>
<td>167 (2.29)</td>
<td>160 (2.01)</td>
<td>168 (1.94)</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>111 (0.66)</td>
<td>109 (0.68)</td>
<td>108 (0.68)</td>
<td>111 (0.67)</td>
</tr>
<tr>
<td>Handgrip strength (kg)</td>
<td>19.41 (0.28)</td>
<td>20.88 (0.34)</td>
<td>23.93 (0.39)</td>
<td>18.30 (0.29)</td>
</tr>
<tr>
<td>PA (d/wk)</td>
<td>3.39 (0.15)</td>
<td>3.48 (0.21)</td>
<td>3.73 (0.22)</td>
<td>2.92 (0.14)</td>
</tr>
<tr>
<td>Estimated V̇O₂ max (mL/kg/min)</td>
<td>40.28 (0.62)</td>
<td>43.54 (0.52)</td>
<td>44.16 (0.69)</td>
<td>33.51 (0.49)</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>21.57 (0.72)</td>
<td>20.54 (0.67)</td>
<td>20.00 (0.77)</td>
<td>21.43 (0.61)</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>38.28 (0.49)</td>
<td>34.74 (0.44)</td>
<td>34.00 (0.46)</td>
<td>39.46 (0.53)</td>
</tr>
<tr>
<td>FFMI (kg/m²)</td>
<td>15.84 (0.14)</td>
<td>14.84 (0.20)</td>
<td>14.78 (0.20)</td>
<td>16.47 (0.34)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>15.84 (0.14)</td>
<td>14.84 (0.20)</td>
<td>14.78 (0.20)</td>
<td>16.47 (0.34)</td>
</tr>
<tr>
<td>Waist-to-hip ratio</td>
<td>34.41 (0.73)</td>
<td>25.29 (0.61)</td>
<td>19.44 (0.44)</td>
<td>34.02 (0.56)</td>
</tr>
<tr>
<td>FFM index (kg/m²)</td>
<td>19.54 (0.14)</td>
<td>18.44 (0.20)</td>
<td>18.40 (0.20)</td>
<td>19.43 (0.15)</td>
</tr>
<tr>
<td>PA (d/wk)</td>
<td>3.39 (0.15)</td>
<td>3.48 (0.21)</td>
<td>3.73 (0.22)</td>
<td>2.92 (0.14)</td>
</tr>
</tbody>
</table>

Descriptive characteristics are presented in Table 1, as means and SE differences. DBP, diastolic blood pressure; LDL, low-density lipoprotein.

* Significant difference between low strength and high strength (P < .05).

† Significant difference between Moderate strength and High strength (P < .05).

‡ Significant difference between females versus males, in equivalent strength categories (P < .05).

§ Significant difference between low strength and Moderate strength (P < .05).
or high strength tertiles (boys: 3.7 days; girls: 3.2 days); nor was there a difference in the frequency of adolescents, across tertiles, who met the cutoff for being “physically active” (boys: 33%–36%; girls: 27%–30%; P > .05). Boys were more physically active than girls across strength tertiles.

**Independent Predictors of Single Risk Components**

Each risk factor was correlated with at least 1 cardiometabolic component among girls and/or boys (Table 2). Therefore, they were all used in a multiple regression model to test the independent association with each individual component. Figure 1 demonstrates partial residual scatterplot between strength capacity and MetScore for boys and girls, after adjustment for age, BMI, and estimated VO₂ max.

**Independent Predictors of the MetScore**

Each risk factor was also included in a multiple regression model to test the independent association with the Met-Score (Table 3). After adjusting for model predictors, there were no significant differences between boys and girls. Moreover, BMI was independently associated with the Met-Score after adjustment for covariates, such that higher BMIs, lower CRF, and had significantly lower clinical markers of risk. From the PCA, %BF was associated with all cardiometabolic risk factors and carried the strongest loading coefficient within the continuous MetScore outcome. Moreover, BMI, PA, and normalized strength capacity were the most influential predictors of overall risk, even after controlling for gender, estimated VO₂ max, and age. These factors were independently and robustly associated with the continuous MetScore, such that higher BMIs, lower relative strength capacities, and inactivity were each indicative of elevated score/risk. These findings are contradictory to a widely held belief that low CRF is the primary physiologic driver of cardiometabolic abnormalities across the life span.36,37 They are also in contrast to 2 recent European studies showing that estimates of VO₂ max were equally important to muscular fitness in predicting cardiometabolic profiles in adolescents.20,22 Although any cross-sectional data cannot reveal the true hierarchy of behavioral and fitness characteristics that “cause” changes in prospective health, our data certainly serve to bolster support for early strength acquisition, regular PA participation, and strategies to maintain healthy BMIs and body compositions among children and adolescents.

Indeed, the frequency of overweight and obesity has risen to nearly 1 in every 3 children and adolescents, aged 2 to 19 years.58 This is alarming considering the evidence that links childhood obesity with subsequent metabolic disturbances and chronic disease outcomes. The lifetime risk for type 2 diabetes is estimated to be 40% for children born in the current decade, with an associated loss of >30 quality-adjusted life years.59 In a recent effort to formalize the clinical and health care implications of obesity, the American Medical Association has officially recognized it as a disease.40 Considering that childhood weight status is known to track into adulthood,41 there is a clear public health demand for identifying sustainable behavioral options to circumvent the consequences of a rising obesity epidemic.42 Unfortunately, and despite the fact that RE has gained some recent attention for its potency in enhancing cardiovascular and metabolic health in adolescents,5,10 blanket clinical recommendations still generally entail dietary modification and aerobic PA for the “treatment” of obesity. However, muscular strength capacity may be an equally important component of metabolic fitness among children and adolescents because it provides protection against insulin resistance.25,43 There is also evidence to support the efficacy of an isolated high-intensity
strength training intervention (ie, without additional dietary intervention or aerobic exercise) to safely reduce adiposity among overweight children. The current findings are supportive of this because both boys and girls with greater strength capacities had the lowest %BF and BMIs.

As with all cross-sectional investigations, a limitation of this study is the inability to disentangle the cause–effect relationship between predictors and outcomes. Indeed whether lower relative strength capacities “cause” a decline in health, or if cardiometabolic abnormalities, themselves, are a cause of diminished muscle function (ie, reverse causality), is an interesting and complex topic. Moreover, although handgrip strength is readily used in cross-sectional research and has been shown to be highly correlated with total muscle strength in children and adolescents, it is not necessarily effective for monitoring strength changes in conjunction with whole body resistance training interventions. Lastly, the use of subjectively measured PA participation in children is prone to recall bias, and thus future cross-sectional and longitudinal work is needed to determine the independent contributions of whole body muscular strength, and objectively measured activity as modifiable predictors of cardiometabolic health in this population. Unfortunately, to date, most clinical reports have focused on the safety or efficacy of strength training in pediatrics, rather than its potential viability for specific health outcomes and thus have obscured the respective clinical application. However, a recent study of 1 million adolescent boys revealed that low muscular strength was a risk factor for major causes of death in young adulthood, such as suicide and cardiovascular diseases, and the effect sizes were equivalent to that for well-established risk factors such as elevated BMI. Although future comparative-effectiveness interventions are certainly warranted, to identify optimal combinations of PA modalities and doses, there is strong support for the use of RE interventions to supplement traditional weight loss interventions among pediatric populations.

**CONCLUSIONS**

Greater relative strength and PA are strong factors associated with cardiometabolic health among children, and this was independent of age, gender, and CRF. Specifically, boys and girls with greater strength-to-body mass
ratios had lower BMIs, less body fat, smaller WCs, higher levels of CRF, and significantly lower clinical markers of cardiometabolic risk. %BF was associated with all cardiometabolic risk factors and carried the strongest weight within the continuous MetScore outcome. These findings reinforce the recent international consensus on youth resistance training,6,48 as well as the World Health Organization’s global recommendations on PA for health,47 both of which advocate the importance of RE as a fundamental component of health-related activity in children and adolescents. Therefore, greater clinical attention to and support of early behavioral interventions to increase PA, reduce adiposity, and increase muscular strength capacity are certainly warranted.

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