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 ($\beta = 0.30$), physical inactivity ($\beta = 0.30$), and normalized strength capacity ($\beta = -1.5$) 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

AUTHORS: Mark D. Peterson, PhD, MS,^a William A. Saltarelli, PhD,^b Paul S. Visich, PhD, MPH,^c and Paul M. Gordon, PhD, MPH^d

^aDepartment of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor, Michigan; ^bHuman Performance Laboratory, Central Michigan University, Mt. Pleasant, Michigan; ^cExercise and Sport Performance Department, University of New England, Biddeford, Maine; and ^dDepartment of Health, Human Performance and Recreation, Baylor University, Waco, Texas

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

Drs Peterson and Gordon conceptualized and designed the study, carried out the analyses, and drafted the initial manuscript; Drs Saltarelli and Visich coordinated and supervised data collection, interpreted data, and critically reviewed the manuscript; and all authors approved the final manuscript as submitted.

www.pediatrics.org/cgi/doi/10.1542/peds.2013-3169

doi:10.1542/peds.2013-3169

Accepted for publication Jan 3, 2014

Address correspondence to Paul M. Gordon, PhD, MPH, Department of Health, Human Performance and Recreation, Baylor University, One Bear Place # 97313, Waco, TX 76798-7313. E-mail: paul_m_gordon@baylor.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

Copyright © 2014 by the American Academy of Pediatrics

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: Funding for this project was generously provided by Memorial Healthcare Foundation, as part of the Memorial FIT Kids program, Owosso, MI.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

Emerging evidence has demonstrated the importance of resistance exercise (RE) and strength preservation in the protection against cardiometabolic diseases¹ and early all-cause mortality.^{2–5} Indeed, among adults with and without existing risk factors, numerous studies have reported significantly improved insulin sensitivity and glucose tolerance with structured RE interventions.^{6,7} There is also compelling evidence to support the efficacy of progressive RE for glycemic control among children and adolescents,⁸ even in the absence of weight loss.^{9,10} However, because RE is known to elicit a potent insulin-sensitizing affect for hours after a single bout of training,^{11–13} 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,¹⁴ RE may be a vital component of health-related physical activity for metabolic fitness in children and adolescents.¹⁵ 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.¹⁶ PCA can be effectively used in pediatric cohorts to aid the interpretation of statistical component clustering,¹⁷ as well as for identifying behavioral predictors of risk. Although previous studies have

incorporated similar continuous scores to improve robustness of cardio-metabolic risk assessment in pediatric research,¹⁸ the PCA method also calculates the respective “weight” (ie, 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.¹⁹ 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,^{20–23} 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.²⁴ 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 ($\text{kg} \cdot \text{m}^{-2}$), and obesity prevalence was estimated based on growth chart percentiles developed by the Centers for Disease Control and Prevention (CDC). Children with a BMI ≥ 85 th and < 95 th percentile of age- and gender-specific reference population²⁵ were designated as overweight, and children with BMIs ≥ 95 th 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 = $[0.735 \times \text{sum of skinfolds}] + 1.0$), and females (%BF = $[0.610 \times \text{sum of skinfolds}] + 5.0$). Additionally, a fat-free mass (FFM) index (FFMI) was also calculated as $[\text{FFM (kg)} \cdot \text{height (m)}^{-2}]$, 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 measure 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 (VO_2).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 VO_2 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-Wilks 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 (ie, 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 (ie, 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, FFMs, 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

	Boys			Girls		
	Low Strength (<i>n</i> = 244)	Moderate Strength (<i>n</i> = 223)	High Strength (<i>n</i> = 203)	Low Strength (<i>n</i> = 273)	Moderate Strength (<i>n</i> = 237)	High Strength (<i>n</i> = 241)
Age, y	11.61 (0.04)	11.61 (0.04)	11.74 (0.04) ^{a,b}	11.49 (0.03) ^c	11.44 (0.04) ^c	11.52 (0.04) ^c
Height (cm)	155.09 (0.48)	152.56 (0.55) ^d	152.29 (0.57) ^a	154.29 (0.44)	151.97 (0.49) ^d	152.03 (0.46) ^a
Wt (kg)	59.60 (0.93)	47.49 (0.76) ^d	43.11 (0.61) ^{a,b}	60.64 (0.94)	46.92 (0.72) ^d	43.26 (0.51) ^{a,b}
BMI (kg/m ²)	24.58 (0.31)	20.19 (0.22) ^d	18.44 (0.17) ^{a,b}	25.24 (0.32)	20.13 (0.24) ^d	18.60 (0.15) ^{a,b}
WC, cm	83.98 (0.91)	70.99 (0.67) ^d	66.43 (0.51) ^{a,b}	81.63 (0.83)	69.59 (0.61) ^d	64.89 (0.45) ^{a,b,c}
Waist-to-hip ratio	0.89 (0.01)	0.84 (0.01) ^d	0.82 (0.01) ^a	0.85 (0.01) ^c	0.82 (0.01) ^d	0.79 (0.01) ^a
%BF	34.41 (0.73)	25.29 (0.61) ^d	19.44 (0.45) ^{a,b}	34.02 (0.56)	26.31 (0.64) ^d	23.23 (0.37) ^{a,b,c}
Fat mass (kg)	21.55 (0.72)	12.64 (0.47) ^d	8.59 (0.27) ^{a,b}	21.43 (0.61)	12.91 (0.42) ^d	10.29 (0.26) ^{a,b,c}
FFM (kg)	38.28 (0.49)	34.74 (0.44) ^d	34.60 (0.46) ^a	39.49 (0.53)	34.21 (0.39) ^d	32.96 (0.32) ^{a,c}
FFM index (kg/m ²)	15.84 (0.14)	14.84 (0.20) ^d	14.78 (0.20) ^a	16.47 (0.34)	14.72 (0.20) ^d	14.17 (0.19) ^{a,b}
PA (d/wk)	3.39 (0.15) ^c	3.48 (0.21) ^c	3.73 (0.22) ^c	2.82 (0.14)	2.88 (0.20)	3.20 (0.19)
Estimated V _O ₂ max (mL/kg/min)	40.28 (0.62)	43.54 (0.52) ^d	44.16 (0.69) ^a	33.51 (0.49) ^c	37.37 (0.35) ^{c,d}	36.33 (0.66) ^{a,c}
Handgrip strength (kg)	19.41 (0.28)	20.88 (0.34) ^d	23.93 (0.39) ^{a,b}	18.30 (0.29) ^c	18.94 (0.29) ^c	21.96 (0.27) ^{a,b,c}
Glucose, mg/dL	96 (0.75)	97 (0.64)	95 (0.64) ^b	94 (0.55)	93 (0.62) ^c	94 (0.65)
Triglycerides, mg/dL	103 (4.06)	75 (2.37) ^d	72 (2.21) ^a	105 (3.66)	85 (2.72) ^{c,d}	81 (2.42) ^{a,c}
Total cholesterol, mg/dL	172 (2.23)	167 (2.29)	160 (2.01) ^{a,b}	168 (1.94)	164 (1.94)	158 (1.75) ^{a,b}
HDL cholesterol, mg/dL	50 (0.97)	54 (1.05) ^d	55 (1.01) ^a	49 (0.86)	54 (0.87) ^d	54 (0.94) ^a
LDL cholesterol, mg/dL	104 (2.10)	101 (2.30)	94 (2.32) ^{a,b}	99 (1.65)	95 (1.71) ^c	89 (1.46) ^{a,b,c}
SBP, mm Hg	111 (0.66)	109 (0.68) ^d	108 (0.66) ^a	111 (0.67)	107 (0.63) ^{c,d}	108 (0.62) ^a
DBP, mm Hg	71 (0.56)	70 (0.60)	69 (0.55) ^a	72 (0.54)	69 (0.56) ^d	69 (0.54) ^a

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

^a Significant difference between Low strength and High strength ($P < .01$).

^b Significant difference between Moderate strength and High strength ($P < .01$).

^c Significant difference in females versus males, in equivalent strength categories ($P < .05$).

^d Significant difference between Low strength and Moderate strength ($P < .01$).

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 MetScore (Table 3). After adjusting for model predictors, there were no significant differences between boys and girls. Moreover, BMI was independently associated with an increase in the MetScore, whereas PA participation and normalized strength capacity were negatively associated with it. Gender,

age, and CRF were not associated with MetScore after adjustment for covariates.

DISCUSSION

This study presents a comprehensive look at the independent association between strength capacity and cardiometabolic health profiles in children. There was a substantial difference in cardiometabolic health across normalized strength tertiles, such that boys and girls with greater strength-to-body mass ratios had lower BMIs and %BFs, had smaller WCs, had higher levels of 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.³⁸ 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.³⁹ 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,^{9,10} 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.^{23,43} There is also evidence to support the efficacy of an isolated high-intensity

TABLE 2 Pairwise Correlations for MetScore Risk Factors

	SBP	HDL	LogTG	Glucose	%BF
Boys—					
Age, y	0.05 ^a	−0.08 ^a	0.01	0.02	−0.01
BMI	0.06 ^a	−0.25 ^a	0.36 ^a	0.11 ^a	0.77 ^a
Waist-to-hip ratio	0.12 ^a	−0.10 ^a	0.15 ^a	0.01	0.27 ^a
Estimated VO ₂ max (mL/kg/min)	−0.15 ^a	0.12 ^a	−0.16 ^a	0.02	−0.32 ^a
Normalized strength	−0.16 ^a	0.12 ^a	−0.28 ^a	−0.05	−0.50 ^a
Girls					
Age, y	0.08 ^a	−0.04	0.04	0.01	0.05
BMI	0.40 ^a	−0.28 ^a	0.30 ^a	0.07 ^a	0.74 ^a
Waist-to-hip ratio	0.08 ^a	−0.07 ^a	0.13 ^a	0.02	0.17 ^a
Estimated VO ₂ max (mL/kg/min)	−0.21 ^a	0.12 ^a	−0.08 ^a	0.01	−0.30 ^a
Normalized strength	−0.15 ^a	0.17 ^a	−0.21 ^a	0.02	−0.51 ^a

TG, triglycerides.
^a Significant correlation at $P < .01$.

FIGURE 1

Partial residual scatterplot revealing the correlations between normalized strength capacity and MetScore for boys (a) and girls (b), after adjustment for age, BMI, and estimated VO_2 max.

strength training intervention (ie, without additional dietary intervention or aerobic exercise) to safely reduce adiposity among overweight children.⁴⁴ 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,⁵⁵ 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 outcomes⁴⁵ 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.³ 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.

TABLE 3 Multiple Regression Models for Independent Predictors of PCA-Derived MetScore

Model Predictor(s)	β	SE	t	Pr > t	95% CI	VIF	Adjusted R^2
PCA-derived MetScore							
Gender (reference: boys)	−0.18	0.11	−1.43	0.09	−0.36 to 0.06	1.22	0.40
Age (y)	0.11	0.09	1.24	0.25	−0.06 to 0.28	1.05	
BMI	0.30	0.01	22.25	<0.01	0.27 to 0.32	1.70	
CRF (estimated VO_2 max)	0.01	0.01	0.58	0.56	−0.01 to 0.02	1.29	
Physical inactivity (reference: active)	0.30	0.01	2.75	0.01	0.26 to 0.33	1.02	
Normalized strength capacity	−1.50	0.62	−2.37	0.02	−2.67 to −0.25	1.62	

CI, confidence interval; Pr, probability; t, t-statistic; VIF, variance inflation factor.

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,⁴⁶ 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.

REFERENCES

- Alberga A, Sigal R, Kenny G. Role of resistance exercise in reducing risk for cardiometabolic disease. *Curr Cardiovasc Risk Rep*. 2010;4(5):383–389
- Xue QL, Beamer BA, Chaves PH, Guralnik JM, Fried LP. Heterogeneity in rate of decline in grip, hip, and knee strength and the risk of all-cause mortality: the Women's Health and Aging Study II. *J Am Geriatr Soc*. 2010;58(11):2076–2084
- Ortega FB, Silventoinen K, Tynelius P, Rasmussen F. Muscular strength in male adolescents and premature death: cohort study of one million participants. *BMJ*. 2012;345:e7279
- Ruiz JR, Sui X, Lobelo F, et al. Association between muscular strength and mortality in men: prospective cohort study. *BMJ*. 2008;337(7661):a439
- Artero EG, Lee DC, Ruiz JR, et al. A prospective study of muscular strength and all-cause mortality in men with hypertension. *J Am Coll Cardiol*. 2011;57(18):1831–1837
- van Dijk JW, Manders RJF, Tummers K, et al. Both resistance- and endurance-type exercise reduce the prevalence of hyperglycaemia in individuals with impaired glucose tolerance and in insulin-treated and non-insulin-treated type 2 diabetic patients. *Diabetologia*. 2012;55(5):1273–1282
- Dunstan DW, Daly RM, Owen N, et al. High-intensity resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care*. 2002;25(10):1729–1736
- Lee S, Bacha F, Hannon T, Kuk JL, Boesch C, Arslanian S. Effects of aerobic versus resistance exercise without caloric restriction on abdominal fat, intrahepatic lipid, and insulin sensitivity in obese adolescent boys: a randomized, controlled trial. *Diabetes*. 2012;61(11):2787–2795
- Van Der Heijden GJ, Wang ZJ, Chu Z, et al. Strength exercise improves muscle mass and hepatic insulin sensitivity in obese youth. *Med Sci Sports Exerc*. 2010;42(11):1973–1980
- Shaibi GQ, Cruz ML, Ball GD, et al. Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. *Med Sci Sports Exerc*. 2006;38(7):1208–1215
- Black LE, Swan PD, Alvar BA. Effects of intensity and volume on insulin sensitivity during acute bouts of resistance training. *J Strength Cond Res*. 2010;24(4):1109–1116
- Yardley JE, Kenny GP, Perkins BA, et al. Resistance versus aerobic exercise: acute effects on glycemia in type 1 diabetes. *Diabetes Care*. 2013;36(3):537–542
- Hansen E, Landstad BJ, Gundersen KT, Torjesen PA, Svebak S. Insulin sensitivity after maximal and endurance resistance training. *J Strength Cond Res*. 2012;26:327–334
- Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. *Am J Prev Med*. 2005;28(3):267–273
- Ehrmann DE, Sallinen BJ, IglayReger HB, Gordon PM, Woolford SJ. Slow and steady: readiness, pretreatment weekly strengthening activity, and pediatric weight management program completion. *Child Obes*. 2013;9(3):193–199
- Peterson MD, Liu D, IglayReger HB, Saltarelli WA, Visich PS, Gordon PM. Principal component analysis reveals gender-specific predictors of cardiometabolic risk in 6th graders. *Cardiovasc Diabetol*. 2012;11:146
- Wijndaele K, Beunen G, Duvigneaud N, et al. A continuous metabolic syndrome risk score: utility for epidemiological analyses. *Diabetes Care*. 2006;29(10):2329
- Eisenmann JC. On the use of a continuous metabolic syndrome score in pediatric research. *Cardiovasc Diabetol*. 2008;7:17
- Katzmarzyk PT, Périusse L, Malina RM, Bergeron J, Després JP, Bouchard C. Stability of indicators of the metabolic syndrome from childhood and adolescence to young adulthood: the Québec Family Study. *J Clin Epidemiol*. 2001;54(2):190–195
- García-Artero E, Ortega FB, Ruiz JR, et al. Lipid and metabolic profiles in adolescents are affected more by physical fitness than physical activity (AVENA study) [in Spanish]. *Rev Esp Cardiol*. 2007;60(6):581–588
- Steene-Johannessen J, Anderssen SA, Kolle E, Andersen LB. Low muscle fitness is associated with metabolic risk in youth. *Med Sci Sports Exerc*. 2009;41(7):1361–1367
- Artero EG, Ruiz JR, Ortega FB, et al; HELENA Study Group. Muscular and cardiorespiratory fitness are independently associated with metabolic risk in adolescents: the HELENA study. *Pediatr Diabetes*. 2011;12(8):704–712
- Grøntved A, Ried-Larsen M, Ekelund U, Froberg K, Brage S, Andersen LB. Independent and combined association of muscle strength and cardiorespiratory fitness in youth with insulin resistance and β -cell function in young adulthood: the European Youth Heart Study. *Diabetes Care*. 2013;36(9):2575–2581
- Devaney JM, Thompson PD, Visich PS, et al. The 1p13.3 LDL (C)-associated locus shows large effect sizes in young populations. *Pediatr Res*. 2011;69(6):538–543
- Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC Growth Charts for the United States: methods and development. *Vital Health Stat* 11. 2002; (246):1–190
- Lohman T. *Advances in Body Composition Assessment*. Champaign, IL: Human Kinetics; 1992
- VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA. Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. *Am J Clin Nutr*. 1990;52(6):953–959
- Perloff D, Grim C, Flack J, et al. Human blood pressure determination by sphygmomanometry. *Circulation*. 1993;88(5 pt 1):2460–2470
- Pickering TG, Hall JE, Appel LJ, et al. Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals

- from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. *Circulation*. 2005;111(5):697–716
30. Lowry R, Lee SM, Fulton JE, Kann L. Healthy people 2010 objectives for physical activity, physical education, and television viewing among adolescents: national trends from the Youth Risk Behavior Surveillance System, 1999–2007. *J Phys Act Health*. 2009;6(suppl 1):S36–S45
 31. Jetté M, Campbell J, Mongeon J, Routhier R. The Canadian Home Fitness Test as a predictor for aerobic capacity. *Can Med Assoc J*. 1976;114(8):680–682
 32. Hogrel JY, Decostre V, Alberti C, et al. Stature is an essential predictor of muscle strength in children. *BMC Musculoskel Dis*. 2012;13:176
 33. Wind AE, Takken T, Helders PJ, Engelbert RH. Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? *Eur J Pediatr*. 2010;169(3):281–287
 34. Ruiz JR, Castro-Piñero J, España-Romero V, et al. Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. *Br J Sports Med*. 2011;45(6):518–524
 35. Pate RR, Daniels S. Institute of Medicine report on fitness measures and health outcomes in youth. *JAMA Pediatr*. 2013;167(3):221–222
 36. Carnethon MR, Gulati M, Greenland P. Prevalence and cardiovascular disease correlates of low cardiorespiratory fitness in adolescents and adults. *JAMA*. 2005;294(23):2981–2988
 37. Wei M, Kampert JB, Barlow CE, et al. Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *JAMA*. 1999;282(16):1547–1553
 38. Ogden CL, Carroll MD, Curtin LR, Lamb MM, Flegal KM. Prevalence of high body mass index in US children and adolescents, 2007–2008. *JAMA*. 2010;303(3):242–249
 39. Narayan KM, Boyle JP, Thompson TJ, Sorensen SW, Williamson DF. Lifetime risk for diabetes mellitus in the United States. *JAMA*. 2003;290(14):1884–1890
 40. American Medical Association. AMA adopts new policies on second day of voting at annual meeting: obesity as a disease. 2013. Available at: <http://www.ama-assn.org/ama/pub/news/news/2013/2013-06-18-new-ama-policies-annual-meeting.page>. Accessed November 2013
 41. Singh AS, Mulder C, Twisk JWR, van Mechelen W, Chinapaw MJM. Tracking of childhood overweight into adulthood: a systematic review of the literature. *Obes Rev*. 2008;9(5):474–488
 42. Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. *Lancet*. 2011;378(9793):815–825
 43. Benson AC, Torode ME, Singh MAF. Muscular strength and cardiorespiratory fitness is associated with higher insulin sensitivity in children and adolescents. *Int J Pediatr Obes*. 2006;1(4):222–231
 44. Benson AC, Torode ME, Fiatarone Singh MA. The effect of high-intensity progressive resistance training on adiposity in children: a randomized controlled trial. *Int J Obes (Lond)*. 2008;32(6):1016–1027
 45. McCambridge TM, Stricker PR; American Academy of Pediatrics Council on Sports Medicine and Fitness. Strength training by children and adolescents. *Pediatrics*. 2008;121(4):835–840
 46. Lloyd RS, Faigenbaum AD, Stone MH, et al. Position statement on youth resistance training: the 2014 International Consensus [published online ahead of print September 20, 2013]. *Br J Sports Med*
 47. World Health Organization. Global Recommendations on Physical Activity for Health. Geneva, Switzerland: World Health Organization; 2010