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Active and strong: physical activity, muscular strength, and metabolic risk in children

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Abstract

Objectives: This study explored the associations among physical activity, muscular strength, and metabolic risk among children.

Methods: The sample included 378 Portuguese children (213 girls; 9–11 years). Moderate-to-vigorous physical activity was assessed by accelerometry and children were classified as active (≥60 min/day) or insufficiently active (<60 min/day). Static strength was expressed as the ratio of handgrip strength/body weight and used to classify children as having high (≥P50) or low (<P50) muscular strength. Children were classified into four groups: active and high strength, active and low strength, insufficiently active and high strength, insufficiently active and low strength. A continuous metabolic risk score was computed from cardiometabolic risk factors.

Results: In general, the insufficiently active and low strength group had the worst metabolic risk score, and the active and high strength group had the best. Significant differences were found within physical activity groups for metabolic risk: children classified as "active and high strength" and "insufficiently active and high strength" had better metabolic risk scores than "active and low strength" and "insufficiently active and low strength", respectively.

Conclusions: Muscular strength has a relevant role in attenuating the association between physical inactivity and metabolic risk in children; a further benefit was identified in children with high physical activity and high muscular strength.

KEYWORDS
physical activity, muscular strength, metabolic risk, children

1 | INTRODUCTION

The metabolic syndrome has increased substantially in the pediatric population (Tailor, Peeters, Norat, Vineis, & Romaguera, 2010), suggesting that it is not exclusively an adult health issue. Indeed, the proportion of overweight/obese children with the metabolic syndrome in Europe, Asia, and North America ranges from 18 to 50% (Saland, 2007). Further, according to a recent review, the prevalence of metabolic syndrome in children and adolescents aged 2–19 years ranged from 1.2 to 22.6% in the general population, with rates up to 60% in overweight and obese youth (Tailor et al., 2010). Notwithstanding the role of genetics in explaining variability in metabolic syndrome risk factors (Butte et al., 2005), behaviors and traits such as physical activity and physical fitness are major elements in their emergence and development (Garcia-Artero et al., 2007; Steele, Brage, Corder, Wareham, & Ekelund, 2008).

Existing research has shown a negative association between physical activity levels and metabolic risk factors (Steele et al., 2008). Since high physical activity levels are associated with greater insulin sensitivity (Park, Hong, Lee, &

Kang, 2007), higher HDL cholesterol (Ekelund et al., 2007), lower blood pressure (Ekelund et al., 2007), lower body weight (Fulton et al., 2009), and lower triglycerides (Fulton et al., 2009), physically active children tend to have better metabolic risk profiles than less active children (Andersen et al., 2006).

Similarly, physical fitness has been inversely related to metabolic risk factors in children and adolescents (Du Bose, Eisenmann, & Donnelly, 2007; Eisenmann, Welk, Ihmels, & Dollman, 2007; Garcia-Artero et al., 2007; Ruiz et al., 2009; Steele et al., 2008). However, most of these studies have examined the association between cardiorespiratory fitness and risk factors. Recent evidence reveals the importance of muscular fitness in the prevention of chronic disease, as well as in the development of metabolic risk in adults (Grontved et al., 2015; Jurca et al., 2005) and youth (Artero et al., 2011; Cohen et al., 2014; Ruiz et al., 2009; Steene-Johannessen, Anderssen, Kolle, & Andersen, 2009).

Since the joint relationships among physical activity, muscular strength and metabolic risk has not been extensively explored in previous research, and due to the fact that physical activity and physical fitness levels in youth have declined over the past decades (Albon, Hamlin, & Ross, 2010; Hallal et al., 2012; Muthuri et al., 2014; Tomkinson & Olds, 2007), it is important to understand if muscular strength can attenuate the negative impact of low physical activity on metabolic risk in youth. As such, the aim of the present study was to explore the joint associations of physical activity and muscular strength with metabolic risk factors in children.

2 | METHODS

2.1 | Participants

The present sample includes children aged 9–11 years (5th grade) from 23 schools participating at the Portuguese site of the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) (Katzmarzyk et al., 2013). The recruitment process followed these steps: (1) a random sample of schools were selected from a list provided by the local education board; (2) from available schools, all 5th grade students were invited to participate, and those who were 9–11 years of age were eligible to participate; (3) approximately 30–40 children were selected randomly (50% girls; ranging from 20 to 42 children/school), and the response rate was 95.7%. The ISCOLE study was approved by the relevant school authorities and the University of Porto ethics committee before starting data collection. Written informed consent was obtained from parents or guardians of all children prior to their participation.

From the 777 children in the total sample, a subsample composed of 378 children (213 girls) participated in the current ancillary study, designed to examine the associations among physical activity, muscular strength, and metabolic risk factors. Children with handicaps or diseases, with physical/psychological disorders that impaired their involvement in daily physical activity, or with missing information for any variable were not included in the present study.

2.2 | Procedures

2.2.1 | Anthropometry

Stature, body mass, waist circumference, and sitting height were measured following standard ISCOLE procedures and instrumentation (Katzmarzyk et al., 2013). Each measurement was repeated and a third measurement was made if the difference between the first two was outside the allowable range for each measure and its replica (0.5 cm for stature, waist circumference and sitting height, and 0.5 kg for body mass). The average of the two closest measurements was utilized in analyses.

2.2.2 | Physical activity

Physical activity was monitored using Actigraph GT3X+ accelerometers (ActiGraph, Pensacola, FL). Children were instructed to wear the accelerometer on a belt worn at the waist, on the right mid-axillary line for 7 days or more (including 2 weekend days), 24 h/day. Daytime activities and nocturnal sleep time were separated using an automated algorithm (Barreira et al., 2015; Tudor-Locke et al., 2014). Further, any sequence of $\geq$20 consecutive minutes of zero activity counts was considered nonwear during the awake period (Tudor-Locke et al., 2015). Days of monitoring that were eligible for analysis had to include a minimum of 10 h of awake wear time, and children had to have $\geq$4 days (and $\geq$1 weekend day) to be included in the sample (all 378 children met this criterion), and moderate-to-vigorous physical activity (MVPA) was defined using the cut-points of Evenson, Catellier, Gill, Ondrak, & McMurray (2008) using 15 s epochs. Children were classified as active (mean MVPA $\geq$60 min/day) and insufficiently active children (mean MVPA $<$60 min/day) according to World Health Organization (WHO) guidelines (World Health Organization, 2010).

2.2.3 | Static muscular strength

Static muscular strength was assessed by the handgrip strength test, which was performed while standing, using a digital dynamometer (Takei TKK 5401, Tokyo, Japan). Children were provided a demonstration and verbal instructions, and the dynamometer was adjusted to the participant's hand size when required. The participants were instructed to squeeze the dynamometer with maximal force, using the preferred/dominant hand, holding it away from the body and

with wrist in the neutral position and the elbow extended. One measurement was obtained and the result was recorded in kg. To adjust for the body size effect, the resulting value was divided by body weight and the ratio handgrip/weight was used in all analysis (as previous performed by Cohen et al. (2014)). Further, the 50th sex-specific percentile (P50) of this sample of the handgrip/weight ratio distribution was used to classify children as having high (≥P50) and low (<P50) muscle strength.

2.2.4 | Biological maturation

Biological maturity was estimated using the maturity offset (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). This technique provides an estimate (in years) of the distance (time) from peak height velocity. A positive (+) maturity offset value suggests that the child is beyond their estimated peak height velocity, while a negative (−) maturity offset value indicates that the child has not yet experienced their peak height velocity. The maturity offset method uses regression equations that incorporate sex, age, and growth parameters (sitting height, body mass, and stature).

2.2.5 | Metabolic risk

The metabolic risk factors included in this study were waist circumference, fasting measures of glucose, high-density lipoprotein cholesterol (HDL-C) and triglycerides, and systolic (SBP) and diastolic (DBP) blood pressures. An automated digital Omron sphygmomanometer (5 Series™ Upper Arm Blood Pressure Monitor—BP742, England, UK) was used to measure resting SBP and DBP after subjects had been at rest for at least 10 min (National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents, 2004). The mean of three measurements taken with a 3-min interval between was used. Mean arterial pressure (MAP) was computed as [(SBP-DBP)/3+ DBP]. Finger-stick blood samples were obtained after a 10–12 h fast, and glucose, triglycerides, and HDL-C were analyzed using a Cholestech LDX (Cholestech Corporation, Hayward, CA, USA) point of care analyzer (LDX C, 2003), which is a reliable alternative for screening risk factors, when compared against clinical diagnostic laboratory methods (Panz, Raal, Paiker, Immelman, & Miles, 2005; Villarroel, Salas, Paoli, & Bellabarba, 2006).

A standardized metabolic risk score (zMR) was computed from waist circumference, MAP, glucose, HDL-C, and triglycerides as previously advocated (Eisenmann, 2008). Prior to the computation of the zMR, all risk factors were adjusted for biological maturity and sex using stepwise regression, and the standardized residuals were retained. The sum of the risk factor residuals (with HDL-*z* score multiplied by −1) was computed and used, in its standardized form, in all analyses. A lower zMR indicates better metabolic risk profile (Eisenmann, 2008).

TABLE 1 Descriptive statistics (mean ± standard deviation or percentage and 95% confidence intervals)

Variable	Means ± SD or percentages (%)
Stature (cm)	143.9 ± 6.8
Body mass (kg)	41.1 ± 9.2
Age (years)	10 ± 0.2
Maturity offset (years relative to peak height velocity)	−1.9 ± 0.9
MVPA (min/day)	55.5 ± 21.3
Handgrip (kg)	16.7 ± 3.6
Handgrip/weight ratio (kg/kg)	0.4 ± 0.1
Accelerometer valid days	6.8 ± 0.6
Waist circumference (cm)	66.9 ± 8.5
HDL-C (mg/dl)	52.6 ± 13.1
Triglycerides (mg/dl)	76.5 ± 55.0
Glucose (mg/dl)	89.8 ± 6.9
MAP (mm Hg)	76.8 ± 7.4
Physical activity level (mean/day) (%)	
≥60 min MVPA/day	35.4% (30.6–40.3%)
<60 min MVPA/day	64.6% (59.5–69.3%)

2.3 | Data analysis

Physical activity and muscular strength categories were used to classify participants into four groups as follows: active and high strength (20.9%); active and low strength (14.6%); insufficiently active and high strength (29.1%); insufficiently active and low strength (35.4%). Group mean differences in each of the risk factors and for zMR, were analyzed using ANOVA. A Bonferroni correction for multiple comparisons was also used. Linear regression analyses were also performed to examine the associations of MVPA and muscular strength with zMR: in model 1, MVPA and muscle strength were included separately; while in model 2, the two variables were included together to test the combined effect of them on zMR. Since zMR was previously adjusted by sex and maturity offset, these variables were not included as predictors in any of the models. All analyses were performed using SPSS 20. Statistical significance was set at 5%.

3 | RESULTS

Descriptive statistics for the sample are presented in Table 1. The mean daily MVPA was 55.5 min, and 35.4% of the

TABLE 2 Association of MVPA and muscle strength with zMR

	MVPA		Muscular strength	
	B	*p* value	*B*	*p* value
Model 1	−0.013	0.042	−8.423	<0.001
Model 2	−0.007	0.303	−8.139	<0.001

Model 1 includes each predictor variable separately; Model 2 includes both variables in a mutually adjusted manner.

sample achieved the international daily recommendation of ≥60 min/day. Their mean handgrip strength was 16.7 kg, and the mean maturity offset was −1.9, meaning that children were on average about 2 years before their predicted peak height velocity.

When stratified by the four physical activity and muscular strength groups, children from the "active and high strength" and "active and low strength" groups, as expected, showed higher MVPA values (about 81 min/day and 75 min/day, respectively) than their peers from "insufficiently active and high strength" and "insufficiently active and low strength" (43 min/day for both). In addition, children classified as having high muscle strength ("active and high strength" and "insufficiently active and high strength") showed higher handgrip strength ("active and high strength": 18.3 kg; "inactive and high strength": 17.8 kg; "active and low strength": 15.6 kg; "inactive and low strength": 15.2 kg) and handgrip/weight ratio ("active and high strength" and "inactive and high strength": 0.5; "active and low strength": 0.4; "inactive and low strength": 0.3) than those classified as having low strength.

Regression analysis, presented in Table 2, showed that both MVPA and muscular strength were negatively associated with zMR. However, when adjusted for muscular strength, MVPA was not significantly associated with zMR, but muscular strength remained significantly associated with zMR, even when adjusted for MVPA.

Table 3 presents results from the ANOVAs for the individual risk factors and zMR, across the physical activity-muscular strength groups. In general, the insufficiently active and low strength group had the poorest metabolic risk profile, and the active and high strength group demonstrated the best metabolic risk profile. With the exception of fasting glucose, there were statistically significant differences ($p < 0.05$) among groups for individual risk factors and zMR. Further, significant differences were found within physical activity groups for zMR, where children classified as "active and high strength" and "insufficiently active and high strength" had better metabolic profiles than their peers classified as "active and low strength" and "insufficiently active and low strength", respectively.

4 | DISCUSSION

The present study analyzed the joint roles of muscular strength and physical activity on metabolic risk factors, in a sample of 9- to 11-year-old Portuguese children. A first discussion note from our results is that a high percentage of children in this sample do not comply with the international daily physical activity recommendations. Only 35.4% (95% CI: 31–40) of the children, on average, participated in at least 60 min of daily MVPA. These results are similar to another recent Portuguese study that reported that approximately

TABLE 3 Differences in metabolic risk Indicators and zMR across physical activity-strength groups (mean ± standard error)

	Active		Insufficiently active				
Variables	High MS ($n = 77$)	Low MS ($n = 57$)	High MS ($n = 113$)	Low MS ($n = 131$)	*F*	*p* value	Pairwise comparisons
WC (cm)	63.0 ± 0.7	71.3 ± 1.2	62.7 ± 0.6	70.8 ± 0.7	36.810	<0.001	AHMS < ALMS; AHMS < IALMS; ALMS > IAHMS; IAHMS < IALMS
HDL (mg/dl)	56.5 ± 1.6	52.0 ± 1.4	55.2 ± 1.3	48.3 ± 1.0	8.989	<0.001	AHMS > IALMS; IAHMS > IALMS
TRI (mg/dl)	64.3 ± 3.6	78.1 ± 10.9	71.9 ± 3.3	86.9 ± 5.5	3.162	0.025	AHMS < IALMS
GLU (mg/dl)	89.7 ± 0.9	90.8 ± 0.8	88.9 ± 0.6	90.1 ± 0.6	1.159	0.325	–
MAP (mm Hg)	74.2 ± 0.8	77.2 ± 0.9	75.9 ± 0.6	78.8 ± 0.7	7.087	<0.001	AHMS < IALMS; IAHMS < IALMS
ZMR	−0.9 ± 0.3	0.3 ± 0.3	−0.7 ± 0.2	0.9 ± 0.3	11.329	<0.001	AHMS < ALMS[a]; AHMS < IALMS; IAHMS < IALMS

[a] $p = 0.051$.

MS = muscular strength; WC = waist circumference; TRI= triglycerides; GLU = glucose; MAP: mean arterial pressure; zMR = metabolic risk *z* score. AHMS = active and high muscular strength group; ALMS = active and low muscular strength group; IAHMS = insufficiently active and high muscular strength group; IALMS = insufficiently active and low muscular strength group.

64% of 10- to 11-year-old children did not comply with the international guideline for daily MVPA (Baptista et al., 2012). Further, a recent literature review, using self-reported data, revealed that about 80.3% of youth aged 13–15 years worldwide do not achieve 60 min/day of MVPA (Hallal et al., 2012).

The main purpose of this study was to determine if differences in metabolic risk exist across physical activity and muscular strength groups in children. The "active and high strength" group showed the best metabolic risk profile, whereas the "insufficiently active and low strength" group showed the worst, highlighting the need for more efficient intervention strategies targeting both physical inactivity and low muscular fitness. Given that these behaviors track reasonably well from childhood into adulthood, interventions during childhood could impart lifelong health impacts (Azevedo, Araujo, Cozzensa da Silva, & Hallal, 2007; Eisenmann, Welk, Wickel, & Blair, 2004; Telama et al., 2014; Trudeau, Laurencelle, & Shephard, 2004; Trudeau, Shephard, Arsenault, & Laurencelle, 2003).

Previous studies have identified independent roles for physical activity and muscular strength on metabolic risk and adiposity in youth (Andersen et al., 2006; Artero et al., 2011; Cohen et al., 2014; Ekelund et al., 2007; Fulton et al., 2009; Guinhouya, Samouda, Zitouni, Vilhelm, & Hubert, 2011; Park et al., 2007; Steele et al., 2008; Steene-Johannessen et al., 2009). It is generally suggested that children with higher physical activity levels tend to have better metabolic profiles than those with lower levels (Andersen et al., 2006; Ekelund et al., 2007; Fulton et al., 2009; Park et al., 2007; Steele et al., 2008), and this association is independent of other variable, such as cardiorespiratory fitness or adiposity (Ekelund et al., 2007; Guinhouya et al., 2011). Similarly, the independent role of muscular strength in the prevention of chronic disease in adults (Ruiz et al., 2008), as well as its positive role on metabolic risk indicators in both men and women have been shown (Jurca et al., 2005; Wijndaele et al., 2007). Research in children has also reported a significant association between high muscular strength and a better metabolic profile (Steene-Johannessen et al., 2009). Additionally, the relationship between cardiorespiratory and muscular fitness with metabolic risk in the HELENA study (Artero et al., 2011) indicated that both physical fitness indicators were independently linked to adolescents' metabolic risk. In a similar vein, the ACFIES study (Cohen et al., 2014) also reported similar results, but the association between muscular strength (assessed by the handgrip test) and metabolic risk was stronger and more consistent than the association between cardiorespiratory fitness and metabolic risk. The authors suggested that the cardiometabolic benefits of muscular strength might be related to its association with body composition (a positive association with percentage of lean mass and inverse association with percentage of body fat); however, this is not clear and future studies should be conducted to better clarify this association. Another point that should be taken into account is the fact that differences in these results can be related, not only to sample characteristics, but also to differences in methods used, since Steene-Johannessen et al. (2009) measured cardiorespiratory fitness by a progressive ergometer test, while Cohen et al. (2014) used a field test (20m shuttle run). Furthermore, a relationship between muscular strength in adolescence and premature mortality and cardiovascular disease in adulthood (Ortega, Silventoinen, Tynelius, & Rasmussen, 2012; Timpka, Petersson, Zhou, & Englund, 2014) has reinforced the notion of low muscular strength "as an emerging risk factor for major causes of death in young adulthood" (Ortega et al., 2012, p. 5).

Some limitations of the present study should be discussed. Firstly, only one measure of muscular strength was used (i.e., handgrip strength), assessed in only one hand (the preferred one), and this single test does not cover all aspects of muscular fitness. However, handgrip strength has been shown to be a valid and reliable indicator of overall and upper-body muscle strength as previously reported (Castro-Pinero et al., 2010; Milliken, Faigenbaum, Loud, & Westcott, 2008). Secondly, notwithstanding that glucose is part of the criteria for metabolic syndrome, investigating the association between insulin and physical activity would most certainly provide novel insights about this relationship; however, we do not have insulin data to pursue this issue further. Thirdly, we did not explore the role of socioeconomic status on the results; although this information was available, the presence of significant missing data for this variable would obligate the use of some multiple imputation method and this would create unnecessary complexity in the data analysis. Fourthly, given the relatively small sample size, we were not able to investigate the relationship of metabolic risk and muscular strength within BMI categories which could provide further insights that could be very helpful in designing/implementing interventions. Fifthly, the cross-sectional nature of the present study does not allow any causation statements, and future research should use longitudinal research designs. Sixthly, the sample comes from one region of Portugal, and since it was an opportunistic sample, care must be taken when generalizing the results; however, in data not shown here, some characteristics between our sample and others from previous studies were found to be very similar, namely in the prevalence of overweight/obesity (Sardinha et al., 2011), socioeconomic status (Fundação Francisco Manuel dos Santos, 2013), and physical activity levels (Baptista et al., 2012). However, despite these limitations, this study has significant merits, such as the use of an objective method to measure children's physical activity over an entire week; the use of a robust method to measure muscular

strength; and the use of standardized methods and trained investigators to collect all data.

In conclusion, physical activity and muscular strength are important correlates of metabolic risk in children, meaning that children with high levels of physical activity and muscular strength are more likely to have better metabolic risk profiles. Further, when analyzed together with physical activity, muscular strength seems to play a relevant role in attenuating the effects of low physical activity levels on metabolic risk, since children with higher muscular strength tend to show lower metabolic risk scores than their peers with lower muscular strength. These results suggest that more attention should be given to muscular strength development during childhood and adolescence with the purpose of reducing the development of metabolic risk in the pediatric population.

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