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PEDIATRIC ORIGINAL ARTICLE

Influence of physical fitness on cardio-metabolic risk factors in European children. The IDEFICS study

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OBJECTIVE: The aim of the study was to assess the associations of individual and combined physical fitness components with single and clustering of cardio-metabolic risk factors in children.

SUBJECTS/METHODS: This 2-year longitudinal study included a total of 1635 European children aged 6–11 years. The test battery included cardio-respiratory fitness (20-m shuttle run test), upper-limb strength (handgrip test), lower-limb strength (standing long jump test), balance (flamingo test), flexibility (back-saver sit-and-reach) and speed (40-m sprint test). Metabolic risk was assessed through *z*-score standardization using four components: waist circumference, blood pressure (systolic and diastolic), blood lipids (triglycerides and high-density lipoprotein) and insulin resistance (homeostasis model assessment). Mixed model regression analyses were adjusted for sex, age, parental education, sugar and fat intake, and body mass index.

RESULTS: Physical fitness was inversely associated with clustered metabolic risk ($P<0.001$). All coefficients showed a higher clustered metabolic risk with lower physical fitness, except for upper-limb strength ($\beta=0.057$; $P=0.002$) where the opposite association was found. Cardio-respiratory fitness ($\beta=-0.124$; $P<0.001$) and lower-limb strength ($\beta=-0.076$; $P=0.002$) were the most important longitudinal determinants. The effects of cardio-respiratory fitness were even independent of the amount of vigorous-to-moderate activity ($\beta=-0.059$; $P=0.029$). Among all the metabolic risk components, blood pressure seemed not well predicted by physical fitness, while waist circumference, blood lipids and insulin resistance all seemed significantly predicted by physical fitness.

CONCLUSION: Poor physical fitness in children is associated with the development of cardio-metabolic risk factors. Based on our results, this risk might be modified by improving mainly cardio-respiratory fitness and lower-limb muscular strength.

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INTRODUCTION

Cardiovascular diseases are the leading cause of death among adults worldwide.[1,2] The biological risk factors for cardiovascular diseases such as abdominal obesity, elevated blood pressure (BP), insulin resistance, elevated triglycerides (TG) and reduced high-density lipoprotein cholesterol (HDL-C) tend to cluster as the metabolic syndrome (MetS), also in children and adolescents.[3] Moreover, metabolic health during childhood can track into adulthood.[4] For prevention and intervention studies, predictors of these MetS risk factors should be identified and their predictive value quantified. Physical activity (PA) is an often cited predictor. PA seemed important to prevent MetS risk factor clustering in 6- to 9-year-old children but less consistent in those 2- to 6-year-old.[5] In contrast with PA, which is related to the movements that people perform, physical fitness (PF) is a set of attributes that people have or achieve and consequently PF has a more direct link with overall health. In the last years, an increasing amount of research on PF and health in childhood and adolescence has been published.[6–21] However, these studies have some weaknesses since they (a) included only one or two PF components, (b) did not include children, that is <9 years, (c) were conducted on small samples, (d) were not longitudinal, or (e) did not adjust for relevant confounders. It is of high public health relevance and importance to understand this relationship more thoroughly in children. Therefore, the primary aim of this study was to assess and quantify longitudinal associations between PF and MetS risk markers in a large sample of European children aged 6–11 years. Herein, we tested whether specific PF components and which single MetS risk outcomes are more or less important.

SUBJECTS AND METHODS

Study population

The current study was based on data derived from the IDEFICS ('IDentification and prevention of dietary and lifestyle induced health EFfects In Children and infantS') study, which was conducted in eight European countries (Belgium, Cyprus, Estonia, Germany, Hungary, Italy, Spain and Sweden). The IDEFICS study aimed to determine the etiology of overweight, obesity and related disorders in children, and to evaluate a tailored primary prevention program.[22,23] Data were collected from a baseline survey (T0; $N=16228$; children aged 2–9 years) and a 2-year

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follow-up survey (T1; $N = 13622$; children aged 4–11 years) in both control regions and intervention regions. Since PF can be measured accurately starting at the age of 6 (ref. 24), only children 6–11 years were included in this study. From the total sample at baseline and follow-up survey, 1635 children had valid data for all tested MetS components (waist circumference, systolic and diastolic blood pressure, TG, HDL-C and homeostasis model assessment (HOMA)), confounders (sex, age, parental educational attainment, sugar and fat propensity score, and body mass index) and PF tests (cardio-respiratory fitness (CRF), upper- and lower-limb strength, speed, flexibility and balance). This large dropout is since PF tests were only performed starting at the age of 6, blood withdrawal was optional and some loss-to-follow-up happened. Included versus excluded subjects did not differ significantly in age, sex, parental educational attainment and body mass index (BMI). The cross-sectional analysis was based on data derived from T0, while a longitudinal analysis was based on change between T0 and T1. The study was approved by the Research Ethics Committees at each national study center involved and was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Edinburgh 2000). Written informed consent was obtained from all parents or guardians.

Measurement protocol

For quality management, all measurements followed detailed standard operating procedures[25] and all field personnel followed training.[22] All study centers used the same technical equipment. The measurements were collected at school and questionnaires were filled in by the parents at home.

Physical fitness assessment

PF components were mostly adapted from the ALPHA health-related fitness test battery, and their reliability and validity have been shown in children of this age.[8,26,27]

Cardio-respiratory fitness. CRF was measured by the progressive 20-m shuttle run test.[28] Participants were required to run between two lines 20-m apart while keeping pace with audio signals emitted from a prerecorded CD. The test was performed using four different versions but results were unified according to the Leger test protocol. The initial speed was 8.5 km h^{-1} and was increased by 0.5 km $h^{-1}min^{-1}$.[28] The test was finished when the participant stopped because of fatigue or failed to reach the end lines concurrent with the audio signals on two consecutive occasions. From the amount of shuttles, maximal oxygen consumption (VO2max) was calculated using Leger´s equation (28). Higher VO2max indicate better CRF. This test was not performed in Italian children ($N = 281$). We did not see important differences when using absolute CRF in the analyses instead of VO2max, except an extra significant association with the insulin resistance. Therefore, only VO2max will be presented.

Muscular strength of upper and lower body. Upper-body isometric strength was measured by the handgrip test. A hand dynamometer with an adjustable grip was used (TKK 5101 Grip D; Takei, Tokyo, Japan). The child had to stay in a standard bipedal position with the elbow in full extension holding the dynamometer without touching any part of the body with it. The dynamometer was adjusted to sex and hand size for each child.[29] The test was performed twice and the maximum score for each hand was recorded in kilograms. The average of the scores achieved by the left and right hands was used in the analysis. Higher scores indicate better performance.

Lower-body explosive strength was measured by the standing long jump test.[30] The child jumped as far as possible with feet together on a nonslip hard surface. The test was performed twice and the best score achieved was recorded in centimeters. Higher scores indicate better performance.

Speed/agility. The 40-m sprint test measured the maximum running speed. The child was instructed to run as quick as he/she can between marker cones spanning over 40 m. Two attempts were allowed, the best score was retained. Lower sprint scores indicate better performance.

The flamingo balance test measured the ability to balance successfully on a single leg. The child has to bend his/her free leg backwards and grip the back foot with his/her hand on the same side. The child was given one try to become familiar with the test. The number of attempts needed to stand on one leg for 1 min was counted for each leg. Children were excluded if they had put down the other foot 15 times or more within the first 30 s. The test score was calculated as the sum of attempts with both legs. Lower scores indicate better performance.

The back-saver sit-and-reach test measured the flexibility of the hamstring muscles.[31] The participant was required to sit with the untested leg bent at the knee; the tested leg was placed straight with the foot placed against the box. The participant slowly reached forward as far as possible. The score was recorded to the nearest centimeter, twice for each leg. The score was calculated as the average of both sides. Higher scores indicate better performance.

Sum of all PF components. The sum was calculated after transforming all PF components to *z*-scores to give all components an equal weight.

Metabolic syndrome

We have considered the recent IDEFICS definition of pediatric MetS, that uses sex- and age-specific cutoffs based on the distribution of all selected MetS components in healthy children.[32] After transforming each continuous component in age- and sex-specific *z*-scores, the sum of the individual components (waist circumference WC, systolic and diastolic blood pressure SBP–DBP, TG-HDL-C and insulin resistance HOMA) was taken. The equation of MetS score was $z_{WC}+(z_{SBP}+z_{DBP})/2+(z_{TRG}-z_{HDL})/2+z_{HOMA}$. As a result, each component had the same weight in the total score. A higher score indicates a less favorable metabolic profile.[32]

Waist circumference. The measurement of waist circumference was obtained twice in the upright position with relaxed abdomen and feet together, midway between the lowest rib margin and the iliac crest to the nearest 0.1 cm with an inelastic tape (Seca 225 stadiometer, Seca, Birmingham, UK).

Blood pressure. Blood pressure was measured with an electronic sphygmomanometer (Welch Allyn 4200B-E2; Welch Allyn Inc., New York, NY, USA)[33] according to a standardized procedure.[34] The cuff length for blood pressure measurement was chosen according to the arm circumference value.[35] Children were asked to sit for at least 5 min before the measurement. Two measurements were taken at 2 min interval and a third measurement was taken if they differed by $>5\%$. The average of the two (or three) measurements was used for statistical analysis.

Blood collection for lipid and glucose homeostasis. Fasting blood was obtained via either vein puncture or via fingertip capillary sampling if participants preferred the latter. In both cases, assessment of blood glucose, HDL-C and TG was done on site at each study center within 5 min of blood withdrawal by placing one drop of blood in the 'point-of-care' analyzer Cholestech LDX (Cholestech, Hayward, CA, USA).[36] A detailed description of the blood sampling procedures and analyses can be obtained from earlier publications.[37] Serum insulin concentrations were measured by luminescence immunoassay in a central laboratory using an AUTO-GA Immulite 2000 (Siemens, Eschborn, Germany). As an indicator of insulin resistance, HOMA[38] was calculated from fasting glucose and insulin according to the following formula: HOMA = fasting insulin (μIU ml^{-a}) fasting glucose (mg dl^{-a})/405.

Possible confounders

Body mass index. BMI was calculated as body weight (kg) divided by height (m) squared. Body weight was measured in underwear with an electronic scale (Tanita BC 420 SMA; Tanita Europe GmbH, Sindelfingen, Germany) to the nearest 0.1 kg. Height was measured barefoot, using a portable stadiometer (Seca 225; Seca) to the nearest 0.1 cm. Age- and sex-adjusted BMI *z*-scores were calculated following Cole's method and obesity/overweight classification was carried out using the extended IOTF cutoffs.[39] We included BMI as confounder since we detected BMI as a longitudinal predictor of PF.

Diet. As a measure for an unhealthy diet, sugar and fat propensity ratios were calculated as published elsewhere.[40]

Physical activity. Accelerometers (Actigraph MTI, model GT1M; Manufacturing Technology Inc., Fort Walton Beach, FL, USA) were worn at the right hip to measure PA. Recordings were considered reliable if the device was worn for at least 6 h per day and for at least 3 days (2 weekdays and 1 day during weekend/holiday).[41] PA was categorized as sedentary, light, moderate or vigorous PA according to the Evenson cutoff points.[42]

Parental education. Parental education as an indicator of socioeconomic status was categorized using the International Standard Classification of Education (ISCED). The ISCED level was derived for the highest qualification levels of both parents using a scale from 0 to 6 but a re-categorization was done as follows: low education attainment (ISCED levels 0–3) and high educational attainment, that is post-secondary education (ISCED levels 4–6).

Socio-demographic data. Age was calculated from examination date and birth date. Information was available whether the child lived in the intervention region or a control region.

Statistical analysis

All statistical calculations were performed in SPSS software, version 22.0 (IBM, New York, NY, USA), with a significance set at two-sided $P < 0.05$. A *post hoc* power calculation showed power > 0.95 for all tests. For descriptive purposes, mean and standard deviation were calculated and Student's paired *t*-test was used to analyze change in predictors and outcome variables between T0 and T1. The associations of the sum PF and its individual components (predictor variables) with the MetS total score and its components (waist circumference, blood pressure, blood lipids and HOMA) were analyzed by linear regression mixed models cross-sectionally and longitudinally. This multilevel method enables a two-level model to adjust for the clustered design (children within countries) by using country as a random factor and to test the longitudinal change (two measurements within the individual, modeled as a slope) by including predictor and outcome factors of the two time points. Adjustments were first done for sex, age, parental education, intervention status (intervention/control region) and diet (model 1); in a second step BMI was added (model 2); and in a third step PA was added (model 3). For longitudinal analyses, data from T0 and T1 (i.e. the slope over time) were used for both predictor and outcome. After all, PF changed over this 2-year period, even after adjusting for all the confounders, so we should take this change into account.

First, we tested the influence of the sum of all PF components on MetS. To highlight which PF component had more effect on MetS, we then tested the PF components separately. To better understand the association between individual PF components and single MetS components, the effect of individual PF component was tested and quantified for each single MetS component separately.

RESULTS

Descriptive characteristics are shown in Table 1. There were significant differences in all PF and MetS components between T0 and T1 ($P < 0.001$). These data reflected an increasing prevalence of MetS by age and an enhancement of fitness level by age except for a decrease in CRF presented by VO2max and flexibility. Although boys performed better than girls in CRF, upper- and lower-limb strength and speed, girls were better in balance and flexibility (results not shown in the table). No sex differences were found in the MetS. Of the selected participants, 10.3% had values of at least three of the MetS components exceeding the 90th percentile (which can be seen as a group that needs close monitoring), whereas 4.7% had values of at least three of MetS components exceeding the 95th percentile (which can be seen as a group that needs intervention).

As can be seen in Table 2, there was a significant inverse association between the PF sum (predictors) and clustered metabolic risk (outcome) only cross-sectionally ($\beta = -0.314$). This relationship was maintained also after adjustment for BMI and PA. Cross-sectionally, all individual PF components were significantly associated with MetS, also after adjustment for BMI and PA. All coefficients showed a higher MetS risk with lower PF performance but opposite directions were found for upper-limb strength. While upper-limb strength had the highest effect size ($\beta = 0.371$), the effect size of lower-limb strength was the highest after adjustment for BMI ($\beta = -0.111$). When adding all PF components together in one model, only the speed component lost its significant value (data not shown in table).

Longitudinally, CRF, lower-limb strength, speed and balance were found to be predictors for MetS. After adjustment for

Table 1. Descriptive characteristics of the study participants ($N = 1635$)

Variables	*T0 (year 2007–2008)*		*T1 (year 2009–2010)*		*P-value: change over time*
	Mean	*s.d.*	*Mean*	*s.d.*	
Predictor variables					
Cardio-respiratory fitness: VO2max (ml kg^{-1} min^{-1})	46.7	4.5	45.0	4.1	< 0.001
Upper-limb strength: handgrip (kg)	11.1	2.7	14.7	3.2	< 0.001
Lower-limb strength: standing long jump (cm)	106.5	22.3	122.2	24.8	< 0.001
Speed: 40-m run[a] (s)	9.1	1.0	8.3	0.8	< 0.001
Balance: flamingo test[a] (attempts)	3.6	3.3	1.9	1.6	< 0.001
Flexibility: sit-and-reach test (cm)	20.9	5.2	19.8	5.8	< 0.001
Included confounding variables					
Age (years)	8.4	1.6			
Sugar propensity in diet (%)	24.7	11.2			
Fat propensity in diet (%)	27.3	10.5			
BMI *z*-score	0.21	1.31			
MVPA (%)	6	3			
Sex: girls (%)	49.7				
ISCED: low level (%)	45.5				
Outcome variables					
Waist circumference (cm)	54.9	6.9	59.4	8.6	< 0.001
SBP (mmHg)	100.8	8.9	104.4	9.0	< 0.001
DBP (mmHg)	63.2	6.4	64.5	6.3	< 0.001
Triglycerides (mg dl^{-1})	56.5	22.7	59.9	29.2	< 0.001
HDL (mg dl^{-1})	52.3	14.0	53.6	14.0	< 0.001
HOMA	0.93	0.86	1.45	1.14	< 0.001
Total MetS score	0.28	2.70	0.88	2.93	< 0.001

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; HDL, high-density lipoprotein; HOMA, homeostasis model assessment; ISCED, International Standard Classification of Education; MetS, metabolic syndrome; MVPA, moderate-to-vigorous physical activity; SBP, systolic blood pressure; VO2max, maximal oxygen uptake. [a]A higher value for these fitness variables represents a lower fitness. *P*-value significantly less than 0.05 by paired *t*-test.

BMI, the longitudinal effect of speed disappeared. After further adjustment for PA, CRF remained the only significant longitudinal predictor ($\beta = -0.059$). CRF was also the PF component that had the highest effect size in longitudinal analyses. When adding all PF components together in one model, lower-limb strength was the only component that was a significant longitudinal predictor of MetS (data not shown in table, $\beta = 0.255$, $P = 0.045$).

Next, we examined the effect on single MetS components using model 2 adjustments (see Table 3). Blood pressure was the least predicted by PF but waist circumference, blood lipids and HOMA all seemed to be important outcomes predicted by PF.

Cross-sectionally, all individual PF components were significantly associated with two or three single MetS components. The highest cross-sectional effect was seen on waist circumference for upper-limb strength ($\beta = 0.121$); the highest effect on HOMA for lower-limb strength ($\beta = -0.105$); and the highest effect on blood lipids for speed ($\beta = 0.113$).

Longitudinally, CRF and lower-limb strength were predictors for waist circumference; lower-limb strength and balance for blood lipids; and lower-limb strength for HOMA. The overall highest effect size was found for lower-limb strength on HOMA ($\beta = -0.077$). Nevertheless, all effect sizes were small ($\beta < 0.114$).

Finally, we analyzed data in Tables 2 and 3 split by sex (see Supplementary data). It seems that the MetS and its single components were in some extent more influenced by physical fitness in girls than in boys.

DISCUSSION

The current longitudinal study examined the association between objectively measured PF components (CRF, upper- and lower-limb strength, speed, balance and flexibility) and either clustered or single metabolic risk factors (waist circumference, blood pressure,

Table 2. Effect of physical fitness on metabolic score using different adjustments

Components of PF	*Data*	*Model 1*		*Model 2: adjustment for BMI*		*Model 3: adjustment for MVPA*	
		β	P	β	P	β	P
Sum PF (*N* = 1199)	Cross	−0.314	< **0.001**	−0.200	< **0.001**	−0.200	< **0.001**
	Long	−0.088	0.231	−0.064	0.217	−0.063	0.324
CRF-VO2max (ml kg^{-1} min^{-1}) (*N* = 1199)	Cross	−0.246	< **0.001**	−0.079	< **0.001**	−0.073	**0.001**
	Long	−0.124	< **0.001**	−0.057	**0.007**	−0.059	**0.029**
Upper-limb strength (kg) (*N* = 1556)	Cross	0.371	< **0.001**	0.055	< **0.001**	0.057	**0.002**
	Long	−0.049	0.052	−0.025	0.166	−0.034	0.149
Lower-limb strength (cm) (*N* = 1598)	Cross	−0.308	< **0.001**	−0.111	< **0.001**	−0.111	< **0.001**
	Long	−0.076	**0.002**	−0.038	**0.025**	−0.038	0.220
Speed (s)[a] (*N* = 1138)	Cross	0.284	< **0.001**	0.126	< **0.001**	0.150	< **0.001**
	Long	0.089	**0.020**	0.026	0.340	0.033	0.336
Balance (attempts)[a] (*N* = 1490)	Cross	0.266	< **0.001**	0.091	< **0.001**	0.080	**0.001**
	Long	0.102	**0.001**	0.045	**0.032**	0.039	0.147
Flexibility (cm) (*N* = 1615)	Cross	−0.034	0.062	−0.050	< **0.001**	−0.038	**0.017**
	Long	−0.034	0.176	−0.008	0.637	−0.000	0.976

Abbreviations: CRF, cardio-respiratory fitness; cross, cross-sectional; long, longitudinal; MVPA, moderate-to-vigorous physical activity; PF, physical fitness; β, standardized coefficients. Model 1: mixed models regression adjusted for sex, age, level of parental educational attainment, sugar and fat propensity score. Model 2: additional adjusted for BMI. Model 3: additional adjustment for MVPA. [a]A higher value for these fitness variables represents a lower fitness. *P*-value < 0.05 means significant. The bold values indicate significant *P*-value.

Table 3. Effect of physical fitness components on separate components of the metabolic score

	Data	*Waist circumference*		*Blood pressure*		*Blood lipids*		*HOMA*	
		β	P	β	P	β	P	β	P
Sum PF	Cross	−0.175	< **0.001**	0.013	0.488	−0.194	< **0.001**	−0.205	< **0.001**
	Long	−0.034	0.409	−0.017	0.730	−0.086	0.077	−0.079	0.264
CRF-VO2max (ml kg^{-1} min^{-1}) (*N* = 1199)	Cross	−0.074	< **0.001**	−0.015	0.323	−0.052	**0.001**	−0.058	**0.005**
	Long	−0.050	**0.004**	−0.003	0.881	−0.023	0.224	−0.052	0.069
Upper-limb strength (kg) (*N* = 1556)	Cross	0.121	< **0.001**	0.024	0.065	−0.009	0.465	0.040	**0.030**
	Long	−0.011	0.418	0.002	0.900	−0.005	0.728	−0.019	0.457
Lower-limb strength (cm) (*N* = 1598)	Cross	−0.086	< **0.001**	−0.013	0.290	−0.080	< **0.001**	−0.105	< **0.001**
	Long	−0.029	**0.026**	−0.018	0.253	−0.058	< **0.001**	−0.077	**0.001**
Speed (s)[a] (*N* = 1138)	Cross	0.112	< **0.001**	0.014	0.513	0.113	< **0.001**	0.078	**0.009**
	Long	0.004	0.826	0.015	0.530	0.034	0.174	0.004	0.907
Balance (attempts)[a] (*N* = 1490)	Cross	0.075	**0.001**	−0.022	0.164	0.051	**0.004**	0.084	**0.001**
	Long	0.000	0.992	−0.025	0.184	0.039	**0.049**	0.048	0.072
Flexibility (cm) (*N* = 1615)	Cross	−0.095	**0.001**	0.038	**0.001**	0.002	0.853	−0.070	**0.001**
	Long	0.008	0.499	−0.007	0.652	0.022	0.151	−0.039	0.098

Abbreviations: CRF, cardio-respiratory fitness; cross, cross-sectional; HOMA, homeostasis model assessment; long, longitudinal; PF, physical fitness; β, standardized coefficients. Mixed models regression adjusted for sex, age, level of parental educational attainment, sugar and fat propensity score and BMI (same adjustments as model 2 in Table 2). [a]A higher value for these fitness variables represents a lower fitness. *P*-value < 0.05 means significant. The bold values indicate significant *P*-value.

blood lipids and HOMA) in European schoolchildren aged 6–11 years.

The relationship between predictors and outcomes was tested in three ways: (i) the association of combined PF (predictor) with clustered metabolic risk (outcome); (ii) the association between individual PF components and clustered metabolic risk; (iii) the prediction on single metabolic risk factors.

(i) The findings in the first test showed a strong evidence for an inverse association between PF and clustered metabolic risk in cross-sectional analysis, also after adjustment for BMI and PA. These results indicated the independent and crucial effect of PF on clustered metabolic risk in young children. However, this association disappeared in the longitudinal analyses. This lack of overall longitudinal effect might be explained by the fact that not all PF components have suggestive causal effect on MetS score (e.g. upper-limb strength and flexibility were not significantly associated with MetS score). We are not aware about any study testing the association between combined PF components and clustered metabolic risk in young children, although previous studies examined the independent associations of CRF and muscular strength with either clustered or single metabolic risk factors in older children and adolescents.[6–11,17–20]

(ii) When testing individual PF components, significant inverse associations were found between all individual PF components and clustered metabolic risk in cross-sectional analysis; only the upper-limb strength was positively associated with clustered metabolic risk. The latter positive relationship is not beneficial from a health perspective and is in contrast to what has mostly been published on this topic.[6–10,16,17] The majority of previous studies included children older than 9 years, whereas the mean age of children in our study was 8.4 years. Although the validity of the PF test for this age group has been shown,[29] it might be that during this young age the handgrip is not directly associated with muscular fitness or that upper-limb strength is not associated with clustered metabolic risk.[43] Some authors explained the relation of greater upper-limb strength with higher MetS risk as a result of overweight and obesity.[44]

In contrast to the upper-limb strength results, lower-limb strength had the protective inverse association with clustered metabolic risk in cross-sectional analysis and remained as a predictor longitudinally. Results from previous studies observed that muscular strength (either upper-limb alone or combined upper- and lower-limb) had higher effect than CRF on clustered metabolic risk,[6,10] while other authors found the association of CRF with clustered metabolic risk to be a bit stronger than muscular fitness.[7,8] The present results led us to suggest the same PA recommendations for children as were suggested for youth,[45] that is, including muscle strengthening exercise, especially that for lower-limb strength. The data from our aforementioned results guide us to agree with the suggestion that ‘standing long jump test’ could be considered as a general index of muscular fitness in youth.[30]

CRF had the strongest inverse association with clustered metabolic risk in longitudinal analysis, followed by balance, speed and lower-limb strength. After adjustment for BMI and PA, CRF remained the only significant longitudinal predictor. These findings indicated that CRF is associated with MetS risk factors independently of PA. Our results concur with several studies, indicating that CRF in childhood and adolescence is strongly associated with metabolic risk.[11–15,18,20] Nevertheless, not only CRF but also lower-limb strength, speed and balance were important to some extent for metabolic health outcomes.

(iii) When testing the association between individual PF components and single metabolic risk factors, we observed that waist circumference, blood lipids and HOMA were all relevant outcomes of fitness. Blood pressure was the factor least influenced by individual PF components in cross-sectional as well as in longitudinal analysis. In line with our findings, none of the studies that included blood pressure as PA outcome in adolescents[46–48] observed significant changes. All these studies, like the present one, were conducted in non-clinical children with quite normal levels of blood pressure, in whom blood pressure is not expected to be reduced.[49] On the other hand, a beneficial effect of interventional aerobic activity programs on blood pressure in hypertensive children has been indicated either with normal BMI,[50,51] or with obesity.[52] Flexibility was the only PF component associated with blood pressure; but the direction of the relationship was not favorable from a health perspective. This unexpected relationship was in agreement with the same finding in one observational longitudinal study[53] but the reason why flexibility might be positively related to blood pressure is still not clear, it might be due to confounders or moderators.

CRF showed negative association with single metabolic risk factors (waist circumference, HOMA and blood lipids) in cross-sectional analysis. Similar findings have been reported for waist circumference,[12–14,19,44,48,53,57–59] blood lipids[14,48] and HOMA.[9,18,21,54] However, CRF was a longitudinal predictor only for waist circumference. Participation in high-intensity exercise would contribute in increasing muscle mass and decreasing central body fat.[55] Our results indicated that maintaining high levels of aerobic fitness during early childhood is associated with low levels of abdominal adiposity during adolescence. However, interventional exercise programs in schoolchildren failed to find beneficial effects on blood lipids[46,47,54] and HOMA.[46,48]

Upper-limb strength was surprisingly positively associated with waist circumference and HOMA in cross-sectional analysis. It has been indicated that the excess of adiposity induces increasing fat-free mass in order to support this extra load.[56] This may explain that individuals with an excess of adiposity performed better in non-weight-dependent tests such as handgrip tests.[57] This association between upper-limb strength and waist circumference was consistent with previous ones in Spanish and Belgian adolescents.[44,57–59] The fact that this positive association was also seen for HOMA might be explained by central adiposity as an important stimulator of imbalanced glucose homeostasis.[9]

Lower-limb strength was inversely associated with waist circumference, blood lipids and HOMA, also in longitudinal analyses. It has previously been shown that fit adolescents possess higher levels of lean body mass compared with their unfit counterparts[57] and consequently have a better control over blood lipids and HOMA. The negative association between lower-limb strength and waist circumference,[19,44,53,57–59] blood lipids[17] and HOMA[9,60] was also observed by other authors.

We have noticed that upper-limb strength was the only PF component positively associated with either clustered or single metabolic risk factors, although this association was only detected in cross-sectional analysis. Nevertheless, lower-limb strength was negatively associated with either clustered or single metabolic risk factors cross-sectionally and longitudinally. These findings might lead us to consider lower-limb strength as a superior indicator than upper-limb strength in evaluating the metabolic risk in young children. These findings call for further investigation.

Speed, flexibility and balance had varying inverse effects on waist circumference, blood lipids and HOMA in cross-sectional analysis, while balance was also a longitudinal predictor for blood lipids. These fitness-related training effects include increase in utilization of muscle glycogen, improvement in the body's ability to oxidize intramuscular fatty acids and decrease in blood insulin concentration (an important inhibiting factor to lipid mobilization). Thus, the fitness exercise probably contributed to increased insulin sensitivity by reducing both muscle and liver fat accumulation. It is therefore not surprising that the waist circumference was also negatively influenced. The observed negative association between these components and waist circumference is in line with previous studies.[19,58]

Strengths and limitations

The main strengths of the current study are: (a) a large sample of European children in a young age group; (b) the standardized use of different components of PF and MetS; (c) longitudinal analyses to explore the influence of PF on MetS risk; (d) the adjustment for BMI and PA to observe the independent effect of PF. To our knowledge, no similar studies have been conducted yet.

The current study is subject to certain limitations. Many children did not have valid and complete data for all necessary variables. Thus, the number of included children dramatically decreased in some of the analyses. Also, the study employed a relatively short time of follow-up (2 years) which could not be a long enough duration to judge on the association between PF and MetS in children. Another limitation is the high number of analyses by testing single MetS risk factors separately, as done in Table 3. Therefore, we should consider the explorative character of these specific analyses.

CONCLUSION

The present study showed that lower fitness was associated with less favorable cardio-metabolic health profiles, especially with higher waist circumference and unhealthier blood lipids and insulin resistance. Blood pressure seemed no relevant health outcome of fitness in this group. Concerning the single fitness components, mainly CRF and lower-limb strength were important longitudinal predictors for MetS. As a result, mainly these fitness components should be stimulated in prevention and intervention related to MetS. Often, their effect was even independent of PA and BMI. In contrast, upper-limb strength as measured by handgrip even seemed to be associated with higher metabolic risk, although only cross-sectional significances were found.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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