EDITOR'S CHOICE

Cardiovascular fitness modifies the associations between physical activity and abdominal adiposity in children and adolescents: the European Youth Heart Study

F B Ortega,[1,2] J R Ruiz,[1,2] A Hurtig-Wennlöf,[3] G Vicente-Rodríguez,[1,4] N S Rizzo,[1] M J Castillo,[2] M Sjöström[1]

[1]Unit for Preventive Nutrition, Department of Biosciences and Nutrition at NOVUM, Karolinska Institutet, Huddinge, Sweden; [2]Department of Physiology, School of Medicine, University of Granada, Madrid, Spain; [3]School of Health and Medical Sciences/Clinical Medicine, Örebro University, Örebro, Sweden; [4]EU Health Sciences, University of Zaragoza, Zaragoza, Spain

Correspondence to: Francisco B Ortega, Department of Biosciences and Nutrition at NOVUM, Karolinska Institutet, 14157 Huddinge, Sweden; ortegaf@ugr.es

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ABSTRACT

Objective To examine the associations between physical activity (PA) and abdominal adiposity, as measured by waist circumference, in children and adolescents, and to test whether cardiovascular fitness (CVF) modifies these associations.

Methods PA components were measured by accelerometry in 1075 individuals aged 9 or 15 years old. CVF was measured by a maximal cycling test. Self-reported maternal educational level, body mass index, children's birth weight and television viewing were used as confounders.

Results Linear regression did not show any association between the PA variables and waist circumference, after controlling for sex, age and height. When stratifying by CVF level (low/high), time spent at vigorous PA was inversely associated with waist circumference ($p \leqslant 0.05$) in the low CVF group. Unexpectedly, in the high CVF group, the PA variables were positively associated with waist circumference ($p \leqslant 0.05$). In both groups, the results were unchanged after controlling for the confounders. CVF was inversely associated with waist circumference, after controlling for all PA variables ($p \leqslant 0.01$) and confounders ($p \leqslant 0.01$).

Conclusion CVF is inversely associated with abdominal adiposity and seems to modify the associations between PA and abdominal adiposity. In low-fit children and adolescents, time spent in vigorous PA seems to be the key component linked to abdominal adiposity. This finding should be considered in further development of lifestyle intervention strategies. The results found in the high-fit group need to be confirmed.

Abdominal adiposity, as measured by waist circumference, is associated with a range of risk factors for cardiovascular disease in young people,[1] even within a given body mass index (BMI) category.[2] Factors related to abdominal adiposity should be identified for more efficient health promotion.

Physical activity (PA) is potentially related to abdominal adiposity, but the associations reported so far in this regard are contradictory.[3–7] Even those studies using objective methods for assessing PA have shown contradictory results in relation to abdominal adiposity.[5–7]

Cardiovascular fitness (CVF) reflects the overall capacity of the cardiovascular and respiratory systems and the ability to carry out prolonged exercise. The maximal oxygen consumption (Vo_2max) has long been considered by the World Health Organization as the single best indicator of CVF. CVF seems to be an interacting factor in the relationships between PA and other health outcomes, for example, metabolic risk factors.[8] Whether CVF also interacts in the associations between objectively measured PA and abdominal adiposity remains to be clarified.

CVF has an important genetic component.[9] People genetically predisposed towards having a better fitness level may also be predisposed towards having a lower adiposity status, with PA being less influential. The main hypothesis tested in this study is that those children and adolescents with a low CVF will show a stronger association between PA and abdominal adiposity than their peers with a high CVF level. The purpose of this study was to examine the associations between objectively measured PA and abdominal adiposity in children and adolescents, and to test whether CVF levels modify these associations. Whether the association of CVF with abdominal adiposity is independent of objectively measured PA was also studied.

METHODS

Study population

A total of 557 children aged 9.5 (0.3) years and 518 adolescents aged 15.6 (0.4) years from the Swedish part of the European Youth Heart Study[10] had valid data for waist circumference. Of these subjects, 96% had complete and valid data for sexual maturation status, 88% for maternal educational level, 90% for birth weight, 94% television (TV) viewing, 71% for objectively measured PA and 75% for CVF (ml/min/kg^{FFM}). Study design, sampling procedures, participation rates and study protocol have been reported elsewhere.[11] The study was approved by the Research Ethics Committees of Örebro County Council and Huddinge University Hospital. Written informed consent was obtained from the parents of the children and from both the parents of the adolescents and also from the adolescents themselves.

Physical examination

BMI was calculated as weight/height squared (kg/m^2) and used to define overweight (including obesity).[12]

Waist circumference (cm) was measured with a metal anthropometric tape midway between the lower rib margin and the iliac crest, at the end of gentle expiration. The individuals were classified as having a high or low metabolic risk (hereinafter called high-risk/low-risk waist circumference), according to sex and age-specific waist circumference cutoff values.[13]

Skinfold thicknesses were measured with a Harpenden caliper (Baty International, Burguess Hill, UK), according to the criteria described by Lohman *et al*.[14] Slaughter's equations were used to calculate the percentage of body fat.[15 16] Being above the sex-specific and age-specific 85th percentile of body fat percentage was used as a cutoff value for defining individuals with an excess of total adiposity.[17] Fat-free mass (FFM) was derived by subtracting fat mass from total body weight.

Pubertal stage was assessed by a trained researcher of the same sex as the child, using brief observation, according to Tanner and Whitehouse.[18] Breast development in girls and genital development in boys were used for pubertal classification.

Objectively measured PA

PA was measured over four consecutive days (at least two weekdays and at least one weekend day) with an activity monitor (MTI model WAM 7164, Manufacturing Technology, Fort Walton Beach, Florida) worn at the right hip. At least 3 days of recording, with a minimum of 10 h registration per day was set as an inclusion criterion. The epoch duration was set at 1 min.[5 19]

Total PA was expressed as the total counts recorded, divided by the total daily registered time (counts/min). The time engaged in moderate and vigorous PA was calculated and presented as the average time per day during the complete registration (min/day). Moderate PA (3–6 metabolic equivalents (METs)) and vigorous PA (>6 METs) intensities were based upon cutoff limits published elsewhere.[20] Also, the time spent in at least moderate intensity PA (>3 METs) was calculated (min/day, MVPA).

The accelerometer (CSA/MTI/Actigraph) and the cutoff limits used in this study have shown to be valid for estimating time spent in moderate and vigorous PA in children and adolescents.[21 22]

Cardiovascular fitness

CVF was determined by a maximal cycle ergometer test.[23] The work rate was preprogrammed on a computerised cycle ergometer (Monark 829E Ergomedic, Vansbro, Sweden), to increase every third minute until exhaustion, as follows: (1) In children (boys and girls) with a body weight of 30 kg or more, the initial work rate was set at 25 W increasing by 25 W every third minute, whereas in those children with a body weight lower than 30 kg, the initial work rate was set at 20 W increasing by 20 W every third minute. (2) In adolescent boys, the initial work rate was set at 50 W, increasing by 50 W every third minute, while in adolescent girls, the initial work rate was set at 40 W, increasing by 40 W every third minute.

Heart rate was registered continuously by telemetry (Polar Sport Tester, Kempele, Finland). The criteria for exhaustion were a heart rate ⩾185 beats per minute and a subjective judgment by the test leader that the adolescent could no longer keep up, even after vocal encouragement. The power output (Watts = W) was calculated as $=W_1+(W_2\times t/180)$, where W_1 is a work rate at the last fully completed stage, W_2 is the work rate increment at final incomplete stage, and t is time in seconds at final incomplete stage. The Hansen formula for calculating Vo_2max (ml/min) was 12× calculated power output +5× body weight (in kg).[23] For the analysis, CVF normalised by FFM (ml/min/kg^{FFM}) was used.[24 25]

Confounders

The time spent in TV viewing was self-reported by means of the question "How many hours of TV do you usually watch?" The answer was classed as either ⩽2 h/day or >2 h/day.[26] Parents reported their children's birth weights, and subjects were classed as <2500 g, between 2500 and 4000 g or >4000 g.[27] Maternal height and weight were self-reported, and BMI was calculated. The validity of BMI based on self-reported weight and height in adults has been documented elsewhere.[28] The socioeconomic status was defined by the maternal educational level as below university education and university education.[29 30]

Statistical analysis

The differences between sex and age groups on continuous variables were assessed by two-way ANOVA (with sex and age as fixed factors). After square root transformation of the vigorous PA and total PA, all the residuals showed a satisfactory pattern. Nominal variables were analysed by χ^2 tests.

Multiple regression analyses were used to study the associations of PA variables and CVF with waist circumference. Interaction factors (ie, sex×main exposures and age×main exposures) were considered to evaluate whether age and sex modified the associations of PA variables and CVF with waist circumference. Since no interaction was found, all sex and age groups were analysed together. Height influences the observation of fat accumulation and/or distribution, and it should be accounted for when analysing the associations between any factor and waist circumference.[3 4 31] Multicollinearity among the exposures was not found in any of the models (variance inflation factor was <10 and averaged variance inflation factor ~1.[32] The PA variables were analysed one by one in all the models to avoid multicollinearity. The statistical analysis performed for this study was split into three steps.

- 1. The basic model was composed of sex, age group and height. The PA variables or CVF were added to the basic model in separate models to analyse the associations between the exposures and waist circumference, controlling for sex, age and height.
- 2. The PA variables were consecutively entered into the models together with CVF to examine whether the associations of PA and CVF with waist circumference were independent of each other. Additionally, interaction factors between the main exposure variables (ie, PA variables×CVF) with waist circumference were also analysed.
- 3. Finally, the associations between PA variables and waist circumference were separately analysed by CVF levels (low/high), and those associations in which interactions found were graphically shown. CVF level was dichotomised (low/high) when being below/above the sex- and age-specific median. All the data were analysed in their continuous form, although data were stratified by quartiles of PA (sex- and age-specific) only for illustrative purposes. In the final model, the analyses were additionally controlled for other potential confounders, such as maternal educational, maternal BMI, birth weight and TV viewing.

All calculations were performed using SPSS V.15.0 software for Windows. For all analyses, the significance level was 5%.

Table 1 Descriptive characteristics of the participants

	Children		Adolescents	
	Boys	Girls	Boys	Girls
	(n = 269)	(n = 288)	(n = 238)	(n = 280)
Age (years)	9.5 (0.3)	9.5 (0.4)	15.6 (0.4)	15.5 (0.4)
Sexual maturation status (%)*,†				
Stage I	99	57	1	0
Stage II	1	40	1	0
Stage III	0	3	3	5
Stage IV	0	0	17	45
Stage V	0	0	79	50
Weight (kg)*,†	33.4 (6.2)	33.7 (6.7)	64.2 (10.7)	57.8 (8.8)
Height (cm)*,†	139 (6)	139 (7)	176 (7)	165 (6)
Body mass index (kg/m^2)†	17.2 (2.4)	17.3 (2.4)	20.7 (2.8)	21.2 (2.7)
Prevalence of overweight (including obesity) (%)	13	18	13	13
Waist circumference (cm)*,†	60.7 (6.0)	60.2 (6.1)	73.8 (7.1)	70.0 (6.7)
High-risk waist circumference (%)‡	27.2	28.6	17.4	30.1
Body fat (%)*,†	16.1 (6.3)	18.6 (5.6)	14.0 (6.5)	23.4 (5.5)
Fat-free mass (kg)*,†	27.7 (3.4)	27.0 (3.8)	54.9 (7.3)	43.9 (5.4)
Total PA level (counts/min)*,†,§	805 (259)	665 (189)	557 (199)	490 (154)
Moderate PA (min/day)*,†	185 (50)	159 (41)	65 (31)	58 (22)
Vigorous PA (min/day)*,†,§	35 (23)	24 (15)	16 (12)	11 (10)
Moderate–vigorous PA (min/day)*,†	220 (65)	182 (51)	81 (38)	69 (28)
Vo_2max (l/min)*,†	1.38 (0.2)	1.23 (0.2)	3.27 (0.5)	2.29 (0.4)
Vo_2max (ml/min/kg)*,†	42.3 (6.9)	36.7 (5.3)	51.0 (6.7)	40.2 (5.9)
Vo_2max (ml/min/kg^{FFM})*,†	50.1 (6.8)	45.2 (5.4)	59.3 (6.0)	52.0 (7.1)

FFM, fat-free mass; PA, physical activity; Vo_2max, maximal oxygen consumption.
Values are mean (SD), unless otherwise stated.
*Sex differences were analysed by two-way ANOVA.
†Age group differences were analysed by two-way ANOVA.
‡Sex differences were found only in adolescents.
§Squared-root transformed data were used in the analysis, but raw data are presented.

RESULTS

The descriptive characteristics of the participants are shown in table 1. Boys were more physically active and had a higher CVF level than girls. Compared with girls, boys spent 46% more time in vigorous PA and 14% more time in moderate PA.

Standardised regression statistics reporting the associations of either PA variables or CVF with waist circumference, after controlling for sex, age and height, are shown in table 2. No significant association was found between any of the PA variables and waist circumference. CVF was negatively associated with waist circumference ($p = 0.002$). This association was unaffected when sexual maturation status instead of age was controlled for (data not shown).

Regression analysis statistics when both PA variables and CVF were entered together into the model are shown in table 3. When CVF was in the model, moderate PA and MVPA were positively associated with waist circumference ($p = 0.010$ and $p = 0.031$, respectively). Neither vigorous PA nor total PA were associated with waist circumference, but significant interactions with CVF were found for these variables ($p = 0.005$ and $p = 0.022$, vigorous PA and total PA, respectively). The associations between these two variables and waist circumference by levels of CVF are shown in fig 1. CVF remained negatively associated with waist circumference, after controlling for all PA variables (p values ranging from 0.005 to 0.014).

Table 4 shows the association between PA variables and waist circumference when stratifying by CVF levels. In individuals with a low CVF level, vigorous PA was inversely associated with waist circumference ($p = 0.044$), while total PA showed a borderline inverse association ($p = 0.080$). In individuals with a high CVF level, all the PA variables studied were positively associated with waist circumference (p values ranging from 0.025 to <0.001). The results did not substantially change when the analyses were controlled for maternal educational level, birth weight or TV viewing. Likewise, CVF remained inversely associated with waist circumference after controlling for these confounders (all $p \leqslant 0.01$). All the results remained unaffected after controlling for maternal BMI (data not shown).

The prevalence of being overweight (IOTF cutoff values), having an excess of total fatness (>85th percentile of body fat) and having a high-risk waist circumference (the Bogalusa study cutoff values) were significantly lower in the high CVF group than in the low CVF group (all $p \leqslant 0.05$; data not shown).

DISCUSSION

Young people with low fitness and high fatness levels have an increased risk for metabolic disease[33–37] and require special attention. In this study, the prevalence of being overweight, having an excess of total fat and having a high-risk waist circumference was greater in the low CVF group than in the high CVF group. The group classed as low CVF was actually a low-fit/high-fat group. In this specific group of individuals, high levels of vigorous PA were associated with a lower abdominal adiposity, independently of sex, age and height. This association

Table 2 Associations of objectively measured physical activity (PA) variables and cardiovascular fitness (CVF) with waist circumference in children and adolescents

Models/exposures	β	p Value
Basic model (BM)		
Sex (0 = girls, 1 = boys)	0.018	0.411
Age (0 = children, 1 = adolescents)	0.014	0.787
Height (cm)	0.706	<0.001
BM+main exposures		
Moderate PA (min)	0.073	0.103
Vigorous PA (min)*	−0.033	0.263
MVPA (min)	0.040	0.340
Total PA (counts/min)*	−0.009	0.771
CVF (ml/min/kg^{FFM})	−0.092	0.002

β Standardised linear regression coefficients. MVPA, moderate to vigorous PA. FFM, fat-free mass.
*Squared root transformed.

was not affected by other confounders, such as maternal educational level, birth weight or TV viewing. Maternal adiposity is a more important determinant factor predisposing for abdominal fatness than paternal adiposity at childhood and adolescence.[38] After additional controlling for maternal BMI, similar trends were observed. The fact that vigorous PA might benefit the abdominal adiposity status in those children and adolescents at a higher metabolic risk may have implications for the development and testing of lifestyle intervention models.

Follow-up data support that, in obese children and adolescents, exercise is an effective way to promote favourable changes in body composition (ie, decreases in percentage body fat).[39] High levels of vigorous PA, rather than light/moderate PA, have shown to be associated with a lower total adiposity, estimated from skinfold thicknesses in children and adolescents.[7 40 41] Collectively, the available information suggests that PA of high intensity could play a key role in the associations between PA and adiposity, both total and abdominal, in young people.

The interactions between CVF and PA in relation to abdominal adiposity found in this study suggest that CVF modifies the associations between PA and abdominal adiposity. This is the first study examining how CVF can influence the associations between objectively measured PA and abdominal adiposity in young people. The high CVF level group showed a lower prevalence of being overweight/obese, having an excess of total fat and having a high-risk waist circumference. Our hypothesis was that in this group of people that already had higher fitness and lower fatness, a weak or even no association between PA variables and abdominal adiposity would be observed. However, the results paradoxically showed that, in these individuals with high CVF levels, all PA variables were positively associated with abdominal adiposity. We checked whether this result could be due to the influence of some potential confounders, such as maternal educational level, maternal BMI, birth weight and TV viewing, but the associations were not affected by any of these factors. Other studies involving objective measurements of PA may confirm or disprove these findings. From an energy balance point of view, this finding would be unexplainable in the case that all the factors that actually influence abdominal adiposity were accounted for (something almost impossible to achieve in practical terms). Unmeasured confounding factors, such as genetic variation and energy intake or dietary patterns, could

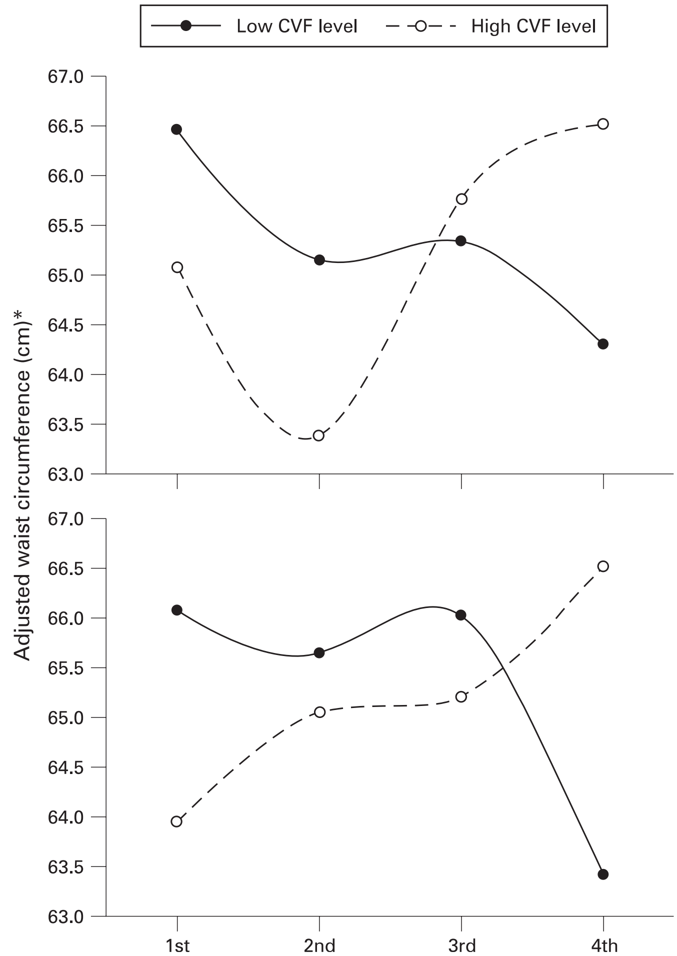

Figure 1 Associations of vigorous physical activity (PA) and total PA, with waist circumference in children and adolescents stratified by cardiovascular fitness level (high/low). The quartiles were sex- and age-specifically calculated.*Waist circumference was adjusted for sex, age and height.

explain these observations. Only randomisation within a trial can deal with issues of unmeasured confounding.

There is evidence indicating that CVF may interact in the associations between adiposity and metabolic risk.[6 36 37 42 43] It has been reported that the deleterious consequences ascribed to high fatness could be counteracted by having high levels of CVF.[36 37 42] This suggests that the positive associations between PA and waist circumference found in the high CVF level group could have lower relevance for the youths' cardiovascular health than in the low CVF level group.

The fact that no interaction by sex or age was found suggests that the associations observed in this study are consistent for children and adolescents, and for boys and girls. The sex differences in the association between PA and abdominal adiposity reported elsewhere[7] is not supported by our results. Methodological differences, such as the different accelerometers used in both studies (uniaxial vs triaxial), might explain the discrepancies.

The findings also indicate that CVF is inversely associated with abdominal adiposity, independently of sex, age, height and all the PA variables. We observed similar results in Spanish adolescents from the AVENA study, yet in that case, PA was self-reported.[4] The fact that CVF is associated with abdominal adiposity in children and adolescents, independently of their

Table 3 Independent associations of objectively measured physical activity (PA) variables and cardiovascular fitness (CVF) with waist circumference in children and adolescents

Basic model+CVF+	Main exposures	β	p (β coefficient)	p Value (interaction)
Moderate PA	CVF (ml/min/kg^{FFM})	−0.102	0.005	0.428
	Moderate PA (min)	0.129	0.010	
Vigorous PA	CVF (ml/min/kg^{FFM})	−0.091	0.014	0.005
	Vigorous PA (min)*	0.011	0.731	
MVPA	CVF (ml/min/kg^{FFM})	−0.102	0.005	0.257
	MVPA (min)	0.101	0.031	
Total PA	CVF (ml/min/kg^{FFM})	−0.095	0.011	0.022
	Total PA (counts/min)*	0.027	0.425	

MVPA, moderate to vigorous PA.
β Standardised linear regression coefficients. Basic model is composed of sex, age group and height.
*Squared root transformed.

objectively measured PA levels, suggests that genetics may play an important role. Sexual maturation status can modify the results and interpretations of analyses concerning CVF in young people,[25] so the analyses were also controlled for maturation. CVF was still significantly associated with abdominal adiposity. Likewise, confounders such as maternal educational level, maternal BMI, birth weight or TV viewing did not substantially affect the associations. The inverse association between physical fitness and abdominal adiposity in young people has been consistently reported. It seems to be independent of the abdominal adiposity measurement method used (high technology methods or anthropometry), the physical fitness testing (running or biking tests) and the physical fitness components used (CVF, muscular fitness or speed/agility).[4 6 7 44–48] This study contributes to the previous literature by reporting that these associations seem also to be independent of total PA and different intensity levels of PA, as measured by objective methods.

Waist circumference has shown to be an accurate marker of abdominal fat accumulation[49] and visceral adiposity[50] in young people. In addition, waist circumference seems to explain the variance in a range of cardiovascular disease risk factors to a similar extent as measurements involving high-technology techniques, including dual energy *x* ray absorptiometry and MRI.[1] Therefore, the use of waist circumference as a surrogate measurement of abdominal adiposity, and as a powerful index associated with metabolic risk in young people, seems to be appropriate for epidemiological studies.

Practical implications

The present study shows that vigorous PA is associated with lower abdominal adiposity in low-fit children and adolescents. Previous studies have demonstrated that meeting the current PA recommendations, that is, 60 min/day of MVPA, is associated with a healthier CVF level but not a lower risk of having high levels of total and central adiposity.[38 51] However, additional analyses support the hypothesis that 60 min or more of daily PA could be enough to achieve a healthier fitness and adiposity status, if enough vigorous PA is accumulated during that period.[52] New PA recommendations adapted to young people, and taking into account the evidence-based importance of vigorous PA, are needed. In this context, sex-specific and age-specific cutoff values for vigorous PA associated with a lower risk of being overweight and having a high-risk waist circumference have been reported by Ortega *et al*:[38] ⩾40 and ⩾25 min/day for children for boys and girls, respectively, and ⩾20 and ⩾15 min/day for adolescent boys and girls, respectively.

Also, regular participation in at least 3 h/week of sports activities and competitions is associated with increased physical fitness, lower whole body and trunkal fat mass in prepubertal boys, compared to those individuals not involved in sport/competition activities.[53] These associations are supported by longitudinal data.[54]

Finally, data from epidemiological studies using objective methods for assessing PA and findings from randomised controlled trials support the idea that high-intensity PA is associated with higher physical fitness and also that physical

Table 4 Associations between objectively measured physical activity (PA) variables and waist circumference in children and adolescents, stratifying by cardiovascular fitness (CVF) level

	Basic model		+Maternal education		+Birth weight		+Television viewing	
	β	p Value	β	p Value	β	p Value	β	p Value
Low CVF								
Moderate PA (min)	−0.016	0.824	−0.031	0.675	0.027	0.714	−0.002	0.997
Vigorous PA (min)*	−0.097	0.044	−0.116	0.019	−0.102	0.039	−0.094	0.060
MVPA (min)	−0.046	0.498	−0.063	0.360	−0.056	0.417	−0.095	0.301
Total PA (counts/min)*	−0.084	0.080	−0.113	0.023	−0.090	0.070	−0.076	0.127
High CVF								
Moderate PA (min)	0.258	<0.001	0.270	<0.001	0.260	<0.001	0.268	<0.001
Vigorous PA (min)*	0.101	0.027	0.101	0.032	0.102	0.030	0.094	0.040
MVPA (min)	0.224	0.001	0.231	0.001	0.229	0.001	0.225	0.001
Total PA (counts/min)*	0.111	0.015	0.110	0.018	0.105	0.026	0.111	0.016

MVPA, moderate to vigorous PA.
Basic model is composed of sex, age group and height. Maternal education, birth weight and television viewing were one by one sequentially added to the basic model.
β Standardised linear regression coefficients.
*Squared root transformed.

What is already known on this topic

Even those studies using objective methods for assessing physical activity have shown contradictory results in relation to abdominal adiposity in young people.

What this study adds

This is the first study examining how CVF can influence the associations between objectively measured physical activity and abdominal adiposity, and whether the association between cardiovascular fitness and abdominal adiposity is independent of objectively measured physical activity in young people.

exercise programs, properly designed and controlled, improve physical fitness in children and adolescents, independently of age, maturation and sex.[43] High-intensity PA seems to be a key element for physical fitness enhancement in young people.

These findings, together with those reported from other cohorts, will help to develop future randomised controlled trials and useful intervention strategies based on lifestyle changes in children and adolescents.

Limitations

The present work, as with any other cross-sectional study, only provides suggestive evidence concerning the causal relationship between PA or CVF and abdominal adiposity. The direction of the cause can be suggested but never certainly stated.

The accelerometers do not compensate for the relative increase in energy expenditure by increase in body size and non-weight-bearing activities such as swimming or cycling are not properly measured by the accelerometers. This could also have been a contribution factor to the unexpected results shown in the high-fit individuals.

The method used for assessing CVF has two main limitations: (1) An inherent error must be assumed when Vo_2max is indirectly estimated. In addition, CVF was expressed as ml/min/kg^{FFM} in this study, and FFM was also indirectly estimated from skinfold thicknesses. (2) Cycling tests give a lower Vo_2max value than running tests.[55] A possible explanation is that on the cycling tests, the limiting influence of undeveloped knee extensor muscle mass induces local muscle fatigue, with subsequent early end of the test. Also, some youths have difficulty maintaining the proper pedal rate.

Strengths

Despite the limitations highlighted above, accelerometry has proven to correlate reasonably with doubly labelled water-derived energy expenditure[21] and is considered nowadays a method of choice for objectively measuring PA in free-leaving children and adolescents. The fact that a relatively large sample of children and adolescents were assessed by means of accelerometry in relation to abdominal adiposity, taking into account CVF measured under well-standardised laboratory conditions and a set of relevant confounders, is a notable strength of this study.

CONCLUSION

CVF seems to modify the associations between PA and abdominal adiposity. In low-fit children and adolescents, time spent in vigorous PA seems to be the key PA component linked to abdominal adiposity. This finding may have important implications for further development of lifestyle intervention strategies, since our data suggest that the individuals with a low CVF are actually a high-risk group. Further research examining genetic and dietary factors, in addition to objectively measured PA and CVF, is still needed for a better understanding of the associations between PA and adiposity in young people. Also, the results found in the high-fit group need to be confirmed or disproved in future studies. Finally, our results show that CVF is inversely and consistently associated with abdominal adiposity, independently of the time spent at different intensities of PA and total PA levels.

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Competing interests None.

REFERENCES

1. **Gutin B,** Johnson MH, Humphries MC, *et al*. Relationship of visceral adiposity to cardiovascular disease risk factors in black and white teens. *Obesity (Silver Spring)* 2007;**15**:1029–35.
2. **Janssen I,** Katzmarzyk PT, Srinivasan SR, *et al*. Combined influence of body mass index and waist circumference on coronary artery disease risk factors among children and adolescents. *Pediatrics* 2005;**115**:1623–30.
3. **Klein-Platat C,** Oujaa M, Wagner A, *et al*. Physical activity is inversely related to waist circumference in 12-y-old French adolescents. *Int J Obes (Lond)* 2005;**29**:9–14.
4. **Ortega FB,** Tresaco B, Ruiz JR, *et al*. Cardiorespiratory fitness and sedentary activities are associated with adiposity in adolescents. *Obesity (Silver Spring)* 2007;**15**:1589–99.
5. **Saelens BE,** Seeley RJ, van Schaick K, *et al*. Visceral abdominal fat is correlated with whole-body fat and physical activity among 8-y-old children at risk of obesity. *Am J Clin Nutr* 2007;**85**:46–53.
6. **Ekelund U,** Anderssen SA, Froberg K, *et al*. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study. *Diabetologia* 2007;**50**:1832–40.
7. **Hussey J,** Bell C, Bennett K, *et al*. Relationship between the intensity of physical activity, inactivity, cardiorespiratory fitness and body composition in 7–10-year-old Dublin children. *Br J Sports Med* 2007;**41**:311–6.
8. **Franks PW,** Ekelund U, Brage S, *et al*. Does the association of habitual physical activity with the metabolic syndrome differ by level of cardiorespiratory fitness? *Diabetes Care* 2004;**27**:1187–93.
9. **Bouchard C,** Rankinen T. Individual differences in response to regular physical activity. *Med Sci Sports Exerc* 2001;**33**:S446–51; discussion S52–3.
10. **Poortvliet E,** Yngve A, Ekelund U, *et al*. The European Youth Heart Survey (EYHS): an international study that addresses the multi-dimensional issues of CVD risk factors. *Forum Nutr* 2003;**56**:254–6.
11. **Wennlof AH,** Yngve A, Sjostrom M. Sampling procedure, participation rates and representativeness in the Swedish part of the European Youth Heart Study (EYHS). *Public Health Nutr* 2003;**6**:291–9.
12. **Cole TJ,** Bellizzi MC, Flegal KM, *et al*. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000;**320**:1240–3.
13. **Katzmarzyk PT,** Srinivasan SR, Chen W, *et al*. Body mass index, waist circumference, and clustering of cardiovascular disease risk factors in a biracial sample of children and adolescents. *Pediatrics* 2004;**114**:e198–205.
14. **Lohman TG,** Roche AF, Martorell R. *Anthropometric standardization reference manual*. Champaign, IL: Human Kinetics, 1991.
15. **Slaughter MH,** Lohman TG, Boileau RA, *et al*. Skinfold equations for estimation of body fatness in children and youth. *Hum Biol* 1988;**60**:709–23.
16. **Rodriguez G,** Moreno LA, Blay MG, *et al*. Body fat measurement in adolescents: comparison of skinfold thickness equations with dual-energy X-ray absorptiometry. *Eur J Clin Nutr* 2005;**59**:1158–66.
17. **Moreno LA,** Blay MG, Rodriguez G, *et al*. Screening performances of the International Obesity Task Force body mass index cut-off values in adolescents. *J Am Coll Nutr* 2006;**25**:403–8.
18. **Tanner JM,** Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. *Arch Dis Child* 1976;**51**:170–9.
19. **Riddoch CJ,** Mattocks C, Deere K, *et al*. Objective measurement of levels and patterns of physical activity. *Arch Dis Child* 2007.
20. **Trost SG,** Pate RR, Sallis JF, *et al*. Age and gender differences in objectively measured physical activity in youth. *Med Sci Sports Exerc* 2002;**34**:350–5.

21. **Plasqui G,** Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity (Silver Spring)* 2007;**15**:2371–9.
22. **Trost SG,** Way R, Okely AD. Predictive validity of three ActiGraph energy expenditure equations for children. *Med Sci Sports Exerc* 2006;**38**:380–7.
23. **Hansen HS,** Froberg K, Nielsen JR, *et al*. A new approach to assessing maximal aerobic power in children: the Odense School Child Study. *Eur J Appl Physiol* 1989;**58**:618–24.
24. **Ekelund U,** Franks PW, Wareham NJ, *et al*. Oxygen uptakes adjusted for body composition in normal-weight and obese adolescents. *Obes Res* 2004;**12**:513–20.
25. **Ortega FB,** Ruiz JR, Mesa JL, *et al*. Cardiovascular fitness in adolescents: The influence of sexual maturation status—The AVENA and EYHS studies. *Am J Hum Biol* 2007;**19**:801–8.
26. **American Academy of Pediatrics**. Committee on Public Education. American Academy of Pediatrics: children, adolescents, and television. *Pediatrics* 2001;**107**:423–6.
27. **Harder T,** Rodekamp E, Schellong K, *et al*. Birth weight and subsequent risk of type 2 diabetes: a meta-analysis. *Am J Epidemiol* 2007;**165**:849–57.
28. **Spencer EA,** Appleby PN, Davey GK, *et al*. Validity of self-reported height and weight in 4808 EPIC-Oxford participants. *Public Health Nutr* 2002;**5**:561–5.
29. **Gnavi R,** Spagnoli TD, Galotto C, *et al*. Socioeconomic status, overweight and obesity in prepuberal children: a study in an area of Northern Italy. *Eur J Epidemiol* 2000;**16**:797–803.
30. **Klein-Platat C,** Wagner A, Haan MC, *et al*. Prevalence and sociodemographic determinants of overweight in young French adolescents. *Diabetes Metab Res Rev* 2003;**19**:153–8.
31. **Hsieh SD,** Yoshinaga H, Muto T. Waist-to-height ratio, a simple and practical index for assessing central fat distribution and metabolic risk in Japanese men and women. *Int J Obes Relat Metab Disord* 2003;**27**:610–6.
32. **Myers R.** *Classical and modern regression with applications*. 2nd ed. Boston, MA: Duxbury, 1990.
33. **Eisenmann JC,** Welk GJ, Ihmels M, *et al*. Fatness, fitness, and cardiovascular disease risk factors in children and adolescents. *Med Sci Sports Exerc* 2007;**39**:1251–6.
34. **Eisenmann JC,** Welk GJ, Wickel EE, *et al*. Combined influence of cardiorespiratory fitness and body mass index on cardiovascular disease risk factors among 8–18 year old youth: The Aerobics Center Longitudinal Study. *Int J Pediatr Obes* 2007;**2**:66–72.
35. **Mesa JL,** Ruiz JR, Ortega FB, *et al*. Aerobic physical fitness in relation to blood lipids and fasting glycaemia in adolescents: influence of weight status. *Nutr Metab Cardiovasc Dis* 2006;**16**:285–93.
36. **Ruiz JR,** Rizzo NS, Ortega FB, *et al*. Markers of insulin resistance are associated with fatness and fitness in school-aged children: the European Youth Heart Study. *Diabetologia* 2007;**50**:1401–8.
37. **Ruiz JR,** Ortega FB, Loit HM, *et al*. Body fat is associated with blood pressure in school-aged girls with low cardiorespiratory fitness: The European Youth Heart Study. *J Hypertens* 2007;**25**:2027–34.
38. **Ortega FB,** Ruiz JR, Sjöström M. Physical activity, overweight and central adiposity in Swedish children and adolescents: the European Youth Heart Study. *Int J Behav Nutr Phys Act* 2007;**4**:61.
39. **Maziekas MT,** LeMura LM, Stoddard NM, *et al*. Follow up exercise studies in paediatric obesity: implications for long term effectiveness. *Br J Sports Med* 2003;**37**:425–9.
40. **Ruiz JR,** Rizzo NS, Hurtig-Wennlöf A, *et al*. Relations of total physical activity and intensity to fitness and fatness in children; The European Youth Heart Study. *Am J Clin Nutr* 2006;**84**:298–302.
41. **Gutin B,** Yin Z, Humphries MC, *et al*. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. *Am J Clin Nutr* 2005;**81**:746–50.
42. **Rizzo NS,** Ruiz JR, Hurtig-Wennlof A, *et al*. Relationship of physical activity, fitness, and fatness with clustered metabolic risk in children and adolescents: the European youth heart study. *J Pediatr* 2007;**150**:388–94.
43. **Ortega FB,** Ruiz JR, Castillo MJ, *et al*. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes (Lond)* 2008;**32**:1–11.
44. **Brunet M,** Chaput JP, Tremblay A. The association between low physical fitness and high body mass index or waist circumference is increasing with age in children: the 'Quebec en Forme' Project. *Int J Obes (Lond)* 2006.
45. **Lee SJ,** Arslanian SA. Cardiorespiratory fitness and abdominal adiposity in youth. *Eur J Clin Nutr* 2007;**61**:561–5.
46. **Winsley RJ,** Armstrong N, Middlebrooke AR, *et al*. Aerobic fitness and visceral adipose tissue in children. *Acta Paediatr* 2006;**95**:1435–8.
47. **Carnethon MR,** Gulati M, Greenland P. Prevalence and cardiovascular disease correlates of low cardiorespiratory fitness in adolescents and adults. *JAMA* 2005;**294**:2981–8.
48. **Janz KF,** Dawson JD, Mahoney LT. Increases in physical fitness during childhood improve cardiovascular health during adolescence: the Muscatine Study. *Int J Sports Med* 2002;**23**(Suppl 1):S15–21.
49. **Taylor RW,** Jones IE, Williams SM, *et al*. Evaluation of waist circumference, waist-to-hip ratio, and the conicity index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3–19 y. *Am J Clin Nutr* 2000;**72**:490–5.
50. **Brambilla P,** Bedogni G, Moreno LA, *et al*. Crossvalidation of anthropometry against magnetic resonance imaging for the assessment of visceral and subcutaneous adipose tissue in children. *Int J Obes (Lond)* 2006;**30**:23–30.
51. **Ortega FB,** Ruiz JR, Hurtig-Wennlof A, *et al*. [Physically active adolescents are more likely to have a healthier cardiovascular fitness level independently of their adiposity status. The European Youth Heart Study]. *Rev Esp Cardiol* 2008;**61**:123–9.
52. **Ortega FB.** *Physical activity, cardiovascular fitness and abdominal adiposity in children and adolescents*. Stockholm: Unit for Preventive Nutrition, Department of Biosciences and Nutrition, Karolinska Institutet, 2008.
53. **Ara I,** Vicente-Rodríguez G, Jimenez-Ramirez J, *et al*. Regular participation in sports is associated with enhanced physical fitness and lower fat mass in prepubertal boys. *Int J Obes Relat Metab Disord* 2004;**28**:1585–93.
54. **Ara I,** Vicente-Rodriguez G, Perez-Gomez J, *et al*. Influence of extracurricular sport activities on body composition and physical fitness in boys: a 3-year longitudinal study. *Int J Obes (Lond)* 2006;**30**:1062–71.
55. **Hermansen L,** Saltin B. Oxygen uptake during maximal treadmill and bicycle exercise. *J Appl Physiol* 1969;**26**:31–7.