Coexistence of obesity and unhealthy cardiorespiratory fitness in a cohort of boys

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ABSTRACT

The aim of the present study was to examine: 1) the coexistence of excessive body weight and low cardiorespiratory fitness (CRF), at a level to be considered unhealthy, and 2) the stability (tracking) of this profile. 1754 European boys, aged 8- to 14-years old, were tested for CRF and based on international cut points were classified as having healthy (H) or unhealthy (UN) CRF. Based on BMI they were classified as having normal weight (N), or overweight or obesity (OO). Chi-square was performed with four groups (i.e. N/H, N/UN, OO/H and OO/UN) and the odds ratios were calculated (cross-sectional analysis). A sub-group of 353 boys were followed for an average of 3.79 ± 0.83 years (range: 2.97−6.06; longitudinal analysis). The odds that a boy was with OO/UN profile compared to the normal body weight category ranged from 2.67 (13-years old) to 6.74 (9-years old). 56.6 % of the participants remained in the same category, whereas 28.0 % of them had ≥ 1 change in category to worst in the second assessment (Cohen Kappa = 0.557, $p < 0.001$; substantial agreement). The odds ratios of having boys with unhealthy profile of combined excessive body weight and low CRF ranged from medium to large. The stability of unhealthy profile was substantial.

Introduction

Obesity and low cardiorespiratory fitness (CRF) are independently associated with unhealthy status and premature death [1, 2, 3], and their combination may exaggerate the problem [4]. Along this line, studies have shown that men with overweight or obesity and low CRF present a greater risk for early death due to cardiovascular diseases than men with normal weight and high CRF [5, 6]. In addition, individuals who are unfit presented a higher risk of mortality, regardless of their body mass index (BMI), compared to normal weight-fit individuals [4].

The prevalence of the unhealthy phenotype, with the coexistence of obesity and low CRF, is unknown in children and adolescents. What is known is that the prevalence of childhood obesity is growing globally, and this is associated with physical and mental health abnormalities [3, 7, 8]. The World Health Organization (WHO) is alerting societies and policymakers on the obesity epidemic, and is calling for actions to combat pediatric obesity in order to ensure the health and wellbeing of societies in the long term [9]. Along this line, evidence suggests that children and adolescents with obesity are five times more likely to become adults with obesity [10]. Obesity in adulthood, in turn, may affect the quality of life negatively and elevate the risk of cardiovascular diseases [7].

Regarding CRF, data show an accelerating decline with age in children and adolescents [11]. Most importantly, the rate of CRF decline is higher in children who are less fit (those in the lowest percentiles), making them vulnerable to obesity-related diseases later in life [11]. The later study of 65,139 children and adolescents reported that performance in the 20-m shuttle run test, which assesses CRF, declined by about 2.9 % from 2005–2009 to 2015–2020 + [11]. The benefits of a high CRF in youth have been well established. Studies show that a high CRF is associated with better body fat distribution with less central obesity [12], better cardiovascular [13, 14], and metabolic function [15, 16]. In the IDEFICS study (Influence of physical fitness on cardio-metabolic risk factors in European children), 1,635 children were followed for 2 years and the results showed that a poor CRF was associated with a worse cardio-metabolic profile [16].

The complications of obesity and low CRF could be exaggerated with the duration of their existence [17]. Accordingly, studies on the stability or tracking of obesity and CRF are important to understand the potential impact of this unhealthy phenotype on health. Evidence suggests that tracking of obesity is moderate to strong in adulthood for children and adolescents with obesity [10]. Additionally, tracking of abdominal obesity, which is independently associated with metabolic dysfunction [18], seems to be high [19]. No study so far has examined the stability of the unhealthy phenotype of being an individual who has overweight or obesity and low CRF in youth.

Therefore, the aim of this study was two-fold: 1) to examine the coexistence of obesity and unhealthy cardiorespiratory fitness in a cohort of children and adolescent boys, and 2) to investigate the stability (tracking) of this phenotype (having overweight or obesity and unhealthy CRF) in a sub-group of participants.

Materials and Methods

Statement of human rights

The study was approved by the university's ethical committee (ERSC_2023_2492; 23/4/2023), and was conducted in accordance with the principles of the Helsinki declaration. Signed informed consent was obtained from the participants' parents.

Participants

1,754 boys, aged 8 to 14 years, participated in this study; all participants were Caucasians of European origin from the same school complex. The tests were conducted as part of the fitness assessment program.

Study design

Baseline measurements were taken between the last week of September and the end of October every year from 2004 to 2021. All measurements were taken in the morning hours during the school program. For those boys who had more than one assessment in the specified period, only the first assessment was considered for the cross-sectional analysis (aim 1). To fulfil aim 2 of this study (tracking), the data from a sub-group of 353 children were used. These 353 children (aged 8 to 11 years) had at least two assessments performed at least 36 months apart during the study period. All assessments were conducted following the same procedure as the one at baseline, and assessments were always performed in the period between the last week of September and the last week of October.

Assessments

Body height was recorded without shoes to the nearest 0.1 cm using a stadiometer (SECA, Hamburg, Germany). Body mass was taken on the same day, wearing light clothes, to the nearest 0.1 kg using a digital scale (SECA, model 770, Hamburg, Germany). Body mass index was calculated and participants were classified as having normal, overweight, or obesity, using the age-related cut points for boys [20]. The cut points to classify a boy as having overweight or obesity are shown in ▶ **Table 1** [20].

Cardiorespiratory fitness was assessed using the 20-m shuttle run test [21]. Participants started running at 8.0 km/h, and the speed was gradually increased by 0.5 km/h every minute until volitional fatigue. The pace was recorded by an audio signal. Children were always made to run between two lines 20 m apart. The actual score of the test was the last stage completed before the boys quit. The test is used worldwide [16, 22, 23], and it is suggested to be a valid tool for the estimation of maximum oxygen uptake [VO_{2max}; 21]. In a previous study with 55 participants of similar age and socioeconomic background to the present study, we have reported a mean difference of 0.13 stages for repeated shuttle-runs with 95 % confidence intervals (CI) between − 0.13 and + 0.39 stages [19]. Based on the test performance, children were classified as having an unhealthy or healthy CRF, using the cut points previously suggested [24]. The suggested cut point for cardiorespiratory fitness to avoid cardiovascular disease risk is equal to a VO_{2max} of 41.8 ml/kg/min in 8- to 18-year-old boys [24], and this is the threshold we used in the present study. This cut point corresponds to one stage completed during the 20-m shuttle run for 8-year-old boys, two stages completed for 9- and 10-year-old boys, three stages for 11-year olds, four stages for 12-year olds, and five stages for 13- and 14-year-old boys [24]. In the meta-analysis of Ruiz and colleagues [24], it was reported that boys with low CRF (estimated

▶ **Table 1** Cut points for BMI (kg/m^2) to classify a boy as having overweight or obesity [20].

Age (years)	Overweight	Obesity
8	18.44	21.60
8.5	18.76	22.17
9	19.10	22.77
9.5	19.46	23.39
10	19.84	24.00
10.5	20.20	24.57
11	20.55	25.10
11.5	20.89	25.58
12	21.22	26.02
12.5	21.56	26.43
13	21.91	26.84
13.5	22.27	27.25
14	22.62	27.63

VO_{2max} below 41.8 ml/kg/min) had a 5.7 times greater likelihood of having CVD risks compared to those with higher CRF.

Statistical analysis

In the cross-sectional part of this study (aim 1), the participants were classified into four groups based on their BMI and CRF: 1) normal BMI with unhealthy CRF (N/UN), 2) normal BMI with healthy CRF (N/H), 3) boys with overweight or obesity with unhealthy CRF (OO/UN), and 4) boys with overweight or obesity with healthy CRF (OO/H). Overweight and obesity were combined together for analyses due to lower sample sizes in the groups. Chi-square tests were used to compare the observed and expected distributions across the groups, and odds ratios (OR) and 95 % CI were calculated for the exposed group (OO/UN: boys who had overweight or obesity and unhealthy CRF). Whenever needed, the Yates' continuity correction was used in the chi-square test. We assumed the existence of an association, if the 95 % CI range did not include a value of 1, and interpreted an OR 1.22 ≤ OR < 1.86 as small, 1.86 ≤ OR < 3.00 as medium, and OR ≥ 3.00 as large [25]. For the tracking analyses, a four-level Cohen's weighted Kappa statistic was used. The proportion of agreement was calculated, i. e. the proportion of children that remained in their class between evaluations. The observed proportions of agreement were compared with the proportions expected given no tracking. Weighted Kappa analyses were performed using a set of weights that are based on the squared distance between categories. We used the guidelines by Muñoz and Bangdiwala [26] to interpret the Kappa coefficients. Benjamini and Hochberg's [27] procedure was applied for multiple testing corrections, and the false discovery rate (FDR) adjusted p-values were reported. FDR-adjusted p-values lower than 0.05 were assumed to be statistically significant. All statistical analyses were conducted using R statistical software (version 4.2.1, R Foundation for Statistical Computing, Vienna, Austria).

Results

The mean age of the participants was 11.4 ± 1.7 years and their BMI was 19.86 ± 3.30 kg/m^2 (mean ± SD; ▶ **Table 2**). The prevalence of normal body mass index, overweight, and obesity in the sample was similar to the national data (65.7 % of the boys in this sample had normal BMI, and 34.3 % had overweight or obesity) [28]. The averages for the 20-m shuttle run are between the 40th and 50th percentile for 8-, 9-, 10-, 11-year-old boys, between the 50th and 60th percentile for 13- and 14-year olds, and between the 60th and 70th percentile for 12-year olds, based on normative values for European boys [22]. The odds that a boy had overweight or obesity and an unhealthy profile for CRF compared to the normal body weight category are 2.67 (13-year old) to 6.74 (9-year old) times higher (▶ **Table 3**).

▶ **Table 2** Participants' characteristics during the first assessment.

Age	N	BMI (kg/m^2)	20-m shuttle run (stages)
Total	*1,754*	*19.9 ± 3.30*	*4.6 ± 2.50*
8	202	18.1 ± 2.61	2.8 ± 1.59
9	200	19.3 ± 3.12	3.2 ± 1.71
10	352	19.2 ± 2.94	3.6 ± 1.74
11	210	20.2 ± 3.10	4.4 ± 2.23
12	513	20.2 ± 3.31	6.0 ± 2.41
13	160	21.4 ± 3.71	5.9 ± 2.35
14	117	21.9 ± 3.07	6.7 ± 2.58

BMI: body mass index.

The mean time interval between measurements varied from 2.97 to 6.06 years, with a mean of 3.79 ± 0.83 years (Median 4.01 years, IQR = 1.05). The average BMI and CRF were 19.12 ± 3.01 kg/m^2 and 3.30 ± 1.68 stages in assessment 1 and 21.50 ± 3.34 kg/m^2 and 6.27 ± 2.17 stages in assessment 2 for these boys, respectively. 56.6 % of the participants remained in the same category, whereas 28.0 % of them had ≥ 1 category (BMI or CRF) changing for the worse (▶ **Table 4**). The Cohen Kappa between the first and last measure was 0.557 ($p < 0.001$), indicating a substantial agreement, meaning that a substantial number of people maintained their position in the second measurement.

Discussion

The main finding of this study is that the odds ratios for boys having unhealthy profiles of combined excessive body weight and low CRF ranged from 2.67 (medium) to 6.74 (large). This unhealthy phenotype shows a substantial stability within an average follow-up period of 3.79 years in this sample. This means that a substantial number of boys maintained their position in the second measurement.

To our knowledge, this is the first study reporting the rate of this unhealthy profile in youth. Assuming that these cut points for the 20-m shuttle run test estimated CRF apply to all populations [24], on average 13 % of the children and adolescents in our sample had overweight or obesity and unhealthy CRF (▶ **Table 3**). We can assume that this unhealthy profile may undermine the physical and mental health of these individuals should this condition remain for a long time [3].

The medium to large odds for the presence of the unhealthy phenotype in the present study (▶ **Table 3**) is an additional alarm for families, school administrators, and policymakers. The WHO declared obesity as a major public health problem and a global epidemic. The medium to large odds (▶ **Table 3**) and the substantial stability of this unhealthy profile (▶ **Table 4**) pose an additional risk for future complications in health when these children become adults. Indeed, previous studies show that children with obesity have a high chance of becoming adults with obesity [29]. In our study, 20 out of 40 boys who had overweight or obesity and unhealthy CRF (50 %) remained in the same category in the follow-up (▶ **Table 4**). Interestingly, 7 out of 20 who shifted categories (35 %) moved to the normal BMI category, whereas 13 out of 20 (65 %) improved the CRF category while maintaining the BMI category. In another study with 374 participants aged 7 to 18, who were followed for 22 years, it was reported that about 83 % of youth who had overweight remained in this category as adults [29]. In addition, the odds of an individual having overweight as an adult were 6.2 times greater in children who had overweight compared to children who had normal body weight [29]. Besides its presence, the duration of obesity will impact the health outcomes [17]. The analysis of the National Health and Nutrition Examination Survey data

▶ **Table 3** Distribution of children and adolescents in our sample in the four groups (N/H: normal BMI with healthy CRF; N/UN: normal BMI with unhealthy CRF; OO/H: boys with overweight or obesity with healthy CRF; OO/UN: boys with overweight or obesity with unhealthy CRF) and odds ratios for the exposed group (OO/UN: boys with overweight or obesity with unhealthy CRF).

Age	n	Distribution, n (%)				χ^2	FDR-adjusted p	Odds ratio (95% CI)
		N/H	N/UN	OO/H	OO/UN			
Total	*1,754*	*963 (54.9)*	*189 (10.8)*	*374 (21.3)*	*228 (13.0)*	100.55	**<0.001**	**3.11 (2.48–3.90)**
8	202	131 (64.9)	6 (3.0)	61 (30.2)	4 (2.0)	0.04	0.845	1.43 (0.39–5.26)
9	200	103 (51.5)	11 (5.5)	50 (25.0)	36 (18.0)	28.29	**<0.001**	**6.74 (3.17–14.34)**
10	352	210 (59.7)	20 (5.7)	87 (24.7)	35 (9.9)	24.17	**<0.001**	**4.22 (2.31–7.72)**
11	210	106 (50.5)	23 (11.0)	49 (23.3)	32 (15.2)	12.09	**<0.001**	**3.01 (1.60–5.67)**
12	513	290 (56.5)	70 (13.6)	86 (16.8)	67 (13.1)	32.51	**<0.001**	**3.23 (2.14–4.88)**
13	160	70 (43.8)	37 (23.1)	22 (13.8)	31 (19.4)	8.29	**0.005**	**2.67 (1.36–5.24)**
14	117	53 (45.3)	22 (18.8)	19 (16.2)	23 (19.7)	128.46	**0.008**	**2.92 (1.33–6.39)**

BMI: body mass index; CRF: cardiorespiratory fitness; FDR, false discovery rate. Values in bold are significant.

▶ **Table 4** Number of participants (n) and percentages (%) in each group considering the first and the second assessment (mean duration between assessments was 3.79 ± 0.83 years with a range from 2.97 to 6.06 years, n = 353).

First assessment		Second assessment			
		Normal BMI with heathy CRF	Normal BMI with unhealthy CRF	Boys with overweight or obesity with healthy CRF	Boys with overweight or obesity with unhealthy CRF
Normal BMI with heathy CRF (n = 204)	n	132	48	20	4
	%	64.7	23.5	9.8	2.0
Normal BMI with unhealthy CRF (n = 20)	n	8	5	1	6
	%	40.0	25.0	5.0	30.0
Boys with overweight or obesity with healthy CRF (n = 89)	n	26	4	43	16
	%	29.2	4.5	48.3	18.0
Boys with overweight or obesity with unhealthy CRF (n = 40)	n	6	1	13	20
	%	15.0	2.5	32.5	50.0

BMI: body mass index; CRF: cardiorespiratory fitness.

in the USA shows that individuals, who were inactive and had overweight or obesity for longer periods, had an increased risk of poor metabolic health compared to those who were active and had overweight. In addition, individuals who had overweight or obesity for longer durations presented an elevated risk of poor metabolic health [17]. A positive message derived from our data is that only a few boys who had normal BMI and healthy CRF at baseline become individuals who have overweight or obesity and unhealthy CRF in the second assessment (4 out of 204, which is less than 3%; ▶ **Table 4**). Overall, our results highlight the role of prevention in body composition and healthy CRF in boys.

The potential beneficial mechanisms explaining the impact of a high CRF on health are related to a better body fat distribution, reduced inflammation and improved metabolic profile [3, 30]. Regarding the body fat distribution, data using magnetic resonance imaging showed that aerobically fit children aged 10.6 years had lower visceral adipose tissue compared to children who are unfit of similar age [31]. Interestingly, children who had overweight or obesity and high CRF presented lower central and total adiposity compared to children in the same BMI category with low CRF [12]. Regarding the improved metabolic profile, we have previously reported improved insulin sensitivity, assessed with the oral glucose tolerance test, after 3 months of aerobic training in youth with overweight or obesity [15]. Interestingly, this improvement in the metabolic profile was associated with an elevation of CRF by 18.8%, without any change in body fat and body mass, suggesting an independent role of a high CRF on metabolic health [15].

Implications of our findings

The implications of our findings in the context of the existing literature discussed above are multiple. Prevention of adoption of the unhealthy profile is key. The achievement of normal BMI and the elevation of CRF should be the primary targets and all stakeholders (families, school administrators, and policymakers) should work towards achieving these goals [32, 33]. The elevation of CRF will be achieved by spending more time in vigorous physical activities.

Limitations

The present study has certain limitations. Obesity was assessed via BMI and CRF via performance in the shuttle run. Both assessments are considered as indirect, and direct measures of body composition and CRF could prove insightful. Our study represents an observational study of a single cohort of European boys. Big scale, representative studies including girls, will be of great value and will allow the generalizability of the findings. The low number of participants in the tracking analysis and the short follow-up period should be considered when interpreting these findings. The maturity stage of these boys was not assessed, and this could also have affected the results. It is acknowledged that CRF is affected by genetics too [34], and we cannot exclude the influence of common genes in body composition and CRF. This would also affect the interpretation of these findings.

Conclusion

The odds of boys having an unhealthy profile of combined excessive body weight and low cardiorespiratory fitness was medium to large. Of note, this unhealthy phenotype presents a substantial stability in the short-term. Future studies should investigate the stability of this profile in the longer term.

Conflict of Interest

The authors declare that they have no conflict of interest.

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