Prevalence of elevated mean arterial pressure and how fitness moderates its association with BMI in youth

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Abstract

Objective: Cardiorespiratory fitness is known to be cardioprotective and its association with the components of the metabolic syndrome in children is becoming clearer. The aim of the present study was to examine the extent to which cardiorespiratory fitness may offset the weight-related association with mean arterial pressure (MAP) in schoolchildren.

Design: Cross-sectional study.

Settings: Schoolchildren from the East of England, UK.

Subjects: A total of 5983 (48% females) schoolchildren, 10 to 16 years of age, had height, weight and blood pressure measured by standard procedures and cardiorespiratory fitness assessed by the 20 m shuttle-run test. Participants were classified as fit or unfit using internationally accepted fitness cut-off points; and as normal weight, overweight or obese based on BMI, again using international cut-off points. Age-adjusted ANCOVA was used to determine the main effects and interaction of fitness and BMI on MAP Z-score. Logistic regression models were used to estimate odds ratios of elevated MAP.

Results: Prevalence of elevated MAP in schoolchildren was 14·8% overall and 35·7% in those who were obese-unfit. Approximately 21% of participants were overweight and 5% obese, while 23% were classified as unfit. MAP generally increased across BMI categories and was higher in the aerobically unfit participants. Obese-fit males had lower MAP compared with obese-unfit males ($P < 0·001$); this trend was similar in females ($P = 0·05$).

Conclusions: Increasing fitness level may have a positive impact on the weight-related elevations of MAP seen in obese and overweight schoolchildren.

The associations between cardiorespiratory fitness, hypertension, all-cause mortality and chronic disease are well established in adults[1,2]. Research shows that cardiorespiratory fitness (fitness) attenuates the negative health consequences of high adiposity (fatness) in adults[3] due to the so-called 'fat but fit' phenomenon[4,5].

Reported secular declines in childhood fitness[6] and increases in adiposity are both alarming and well documented in many developed countries including the UK[7]. As body weight is positively associated with blood pressure (BP)[8], it is unsurprising that a secular increase in children's BP has also been reported[9]. In schoolchildren, that cardiorespiratory fitness is cardioprotective may be well established[10–12], but details of how it interacts with body composition to mediate BP remain inconsistent.

Lee *et al.*[5] examined this 'fit but fat' hypothesis in 21 925 males (aged 30–83 years). Mortality rates after 8 years of follow-up showed that those who were fit enjoyed protection from the potential deleterious health effects of being overweight. Fitness has also been shown to attenuate metabolic risk independent of abdominal adiposity[13]. Stevens *et al.*[14], on the other hand, found no significant interaction between fitness and fatness as predictors of all-cause or cardiovascular mortality. Their study did, however, confirm the efficacy of cardiorespiratory fitness in reducing mortality.

Cardiorespiratory fitness and adiposity are interdependent and controversy remains as to the relative independence of relationships between fitness and fatness in youth. One source of controversy may be the interchange between physical activity and cardiorespiratory fitness as effect modifiers; it is important to note that fitness and physical activity are distinct constructs. Further controversy likely stems from the use of different estimates and cut-off points for fatness (percentage body fat, BMI or waist circumference), the often arbitrary definitions of

cardiorespiratory fitness[11,15] and the study of samples of different age groups[16,17]. Arbitrary cut-off points such as median split of age-adjusted BMI, physical working capacity and values of standardized residuals have been used in previous studies[15,18] rather than more preferable, criterion-referenced classifications.

We attempted to address these deficiencies by using accepted cut-off points for cardiorespiratory fitness and BMI. First, we defined BMI as normal weight, overweight or obese using internationally defined cut-off points based on predicted adult values of <25, 25–30 or >30 kg/m², respectively[19]. We then defined low fitness using a retro-extrapolated cut-off point which predicts an adult value below the 20th percentile and an increased risk of cardiomyopathy[20]. Finally, we assessed how fitness and BMI interact with one another and their subsequent associations with BP in youth. We hypothesized that high levels of fitness would attenuate the relationship between overweight/obesity and BP. Our secondary aim was to evaluate the prevalence of elevated mean arterial pressure (MAP) in English schoolchildren.

Materials and methods

Study population
A total of 5983 schoolchildren aged 10–16 years were recruited from a structured convenience sample of twenty-three state-run, comprehensive schools. All data were collected between 2007 and 2009. We sent letters to schools in the East of England region inviting them to participate and from responders we purposefully selected a sample designed to have characteristics similar to the East of England's population in terms of rural (30 %) or urban dwelling (70 %) and area-level deprivation. All participants were enrolled in the ongoing East of England Healthy Hearts Study. Pupils who normally attended physical education classes were included in the study. Using the exclusion criteria of the presence of known CVD or a lack of parental or pupil consent, we achieved a response rate of >98 % for the measurements made in the present study (2 % of available pupils were withdrawn). The study was approved by the University of Essex Ethics Committee.

Anthropometry
We measured stature to the nearest 1 mm (Seca Leicester Height Measure; Seca GmbH & Co. KG, Hamburg, Germany) and mass to the nearest 0·1 kg (Seca 888 digital scale; Seca GmbH & Co. KG) with participants dressed in T-shirt and shorts, without shoes. BMI was calculated (kg/m²), converted to Z-scores based on UK reference data[19] and categorized as normal weight, overweight or obese according to International Obesity Taskforce (IOTF) criteria[19]. Data required for BMI categorization were missing for 104 participants, reducing the sample size to n 5879.

Cardiorespiratory fitness
Cardiorespiratory fitness was assessed using the 20 m shuttle-run test (20mSRT) administered in the form of the FITNESSGRAM PACER, a modified version of the original protocol[21]. Participants had previously taken part in the 20mSRT as part of their physical education. Participants were encouraged by both the instructions on the PACER CD and a researcher to 'run for as long as possible'. The test requires volunteers to run back and forth over a marked distance of 20 m in time with an audible signal. The test starts at an initial running speed of 8·0 km/h and increases initially by 1 km/h after the first minute and then by 0·5 km/h each minute thereafter. Researchers acted as 'spotters' and recorded the final shuttle count at either the point of volitional exhaustion or when the participant failed to maintain the required running speed twice. Final shuttle count was converted first to final running speed and then into Z-scores based on global performance indices[22]. VO$_{2max}$ (ml/kg per min) was predicted based on final running speed and age[23]. FITNESSGRAM PACER Healthy Fitness Zone cut-offs[20] were used to categorize participants. If participants' total completed shuttle count was above their age- and sex-specific cut-off, they were classed as 'fit'; otherwise they were classified as 'unfit'.

Blood pressure measurement
All BP measurements were carried out after the participant completed a physical activity questionnaire, which typically took 10–12 min. BP was measured after a further 5 min of quiet, seated rest. Trained researchers fitted an appropriately sized inflatable cuff around the upper left arm of each participant. Participants were instructed to sit still in their chair with their left arm resting on a table at the same level as the heart. Two measures of systolic blood pressure (SBP) and diastolic blood pressure (DBP) were made using an automated sphygmomanometer (Omron MX3; Omron Healthcare Europe BV, Hoofddorp, The Netherlands). The lowest measures of SBP and DBP were recorded, since the first reading in a series of BP measurements is typically higher when oscillometric devices are employed[24,25]. All BP measurements were taken before the fitness test. Participants' MAP values (in mmHg) were generated from SBP and DBP values using the following formula:

$$MAP = \frac{2}{3}(DBP) + \frac{1}{3}(SBP).$$

Standardized scores were derived for MAP (Z-score) using the BP reference charts for the UK[8], which adjust for age, sex and skewness.

Deprivation quintile
We obtained an area-level measure of deprivation for each participant using home postcode. The English Index of Multiple Deprivation 2007 (IMD 2007) is measured based on the small-area geographical units known as lower super output areas, details of which have been

described elsewhere[26]. Within the present data, IMD 2007 scores ranged from 1·96 to 62·5. Quintiles of deprivation were generated from the ranked IMD 2007 scores in which the first quintile (1) represented the least deprived and the last quintile (5) the most deprived.

Data analysis

Participants were grouped by fitness (either fit or unfit)[20] and BMI category (normal weight, overweight or obese)[19]. ANCOVA, controlling for age, was used to determine the main effects and interaction of fitness and BMI category on MAP *Z*-score. *Post hoc* analyses were performed using the Bonferroni multiple comparison test. Data were analysed separately for males and females, due to the differences between sexes in BMI, fitness and MAP. Since sex may also be an important determinant of health and illness, analysing data by sex is encouraged[27].

Logistic regression analysis was conducted to calculate odds ratios of elevated MAP from categorical fitness and fatness variables. MAP centiles were generated from age- and sex-specific *Z*-scores and participants were classified as having high or low MAP using the 91st centile cut-off as recommended[8]. Predictors in the regression analysis were weight status (BMI category) and fitness (fit, unfit). In a second model the interaction between BMI category and fitness was also examined. All statistical analyses were performed using the statistical software package PASW Statistics 18.

Results

Participants' SBP, DBP and MAP according to age, gender, BMI category and fitness are shown in Table 1. The overall prevalence of elevated MAP was 15%, but reached 36% in obese schoolchildren who were also unfit. There was a significant difference in MAP between sexes ($P < 0.001$). MAP increased according to age and was higher in the overweight and obese BMI categories as well as in unfit participants ($P < 0.001$). There were no significant between-sex or between-age differences after converting MAP to *Z*-scores ($P > 0.05$).

Overall, 21% of the sample was overweight and 5% obese. In total, 23% of the sample was classified as unfit; this was less common in normal weight (16%) than in either overweight (35%) or obese (63%) participants. The combined influence of fitness and BMI category on MAP is shown separately for males and females in Fig. 1. The MAP *Z*-score of fit-obese schoolchildren was significantly lower than that of unfit-obese ones ($P < 0.001$). The difference in MAP *Z*-score between fit-overweight and unfit-overweight schoolchildren was not significant ($P > 0.05$). In fit participants, VO_{2max} was 48·2 (SD 6·1) ml/kg per min (males) and 43·8 (SD 4·7) ml/kg per min (females), compared with 47·9 (SD 5·3) ml/kg per min (males) and 39·9 (SD 2·6) ml/kg per min (females) in unfit participants.

In males, there were main effects for BMI ($F = 36.64$, $P < 0.001$; MAP *Z*-score mean and SD: 0·33 (SD 0·85) in normal weight (*n* 2268); 0·61 (SD 0·83) in overweight (*n* 649); 0·87 (SD 0·87) in obese (*n* 172)) and cardiorespiratory fitness ($F = 12.31$, $P < 0.001$; MAP *Z*-score mean and SD: 0·53 (SD 0·87) in unfit (*n* 831); 0·39 (SD 0·86) in fit (*n* 2283); Table 2). In females, there were main effects for BMI ($F = 28.83$, $P < 0.001$; MAP *Z*-score mean and SD: 0·36 (SD 0·82) in normal weight (*n* 2059); 0·64 (SD 0·80) in overweight (*n* 590); 0·75 (SD 0·79) in obese (*n* 141)), but not cardiorespiratory fitness ($F = 0.96$, $P = 0.33$; MAP *Z*-score mean and SD: 0·51 (SD 0·82) in unfit (*n* 535); 0·43 (SD 0·83) in fit (*n* 2334)). There was a significant interaction between BMI and cardiorespiratory fitness in males ($F = 7.54$, $P < 0.01$), but not in females ($F = 2.39$, $P = 0.09$). Overall, obese-fit males ($P < 0.001$) and females ($P = 0.05$) had a lower mean MAP *Z*-score than their obese-unfit counterparts (Table 2).

Unadjusted and adjusted odds ratios and 95% confidence intervals of the binary logistic regression predicting elevated MAP (>91st centile) are presented in Table 3. When BMI categories (categorized as normal weight, overweight or obese by IOTF cut-off points) and fitness (dichotomized by FITNESSGRAM cut-off points) were entered into the model, BMI was a significant predictor of elevated MAP; but no other variables added significantly to the prediction of MAP. Obese schoolchildren were over three times more likely to have a high MAP than normal-weight schoolchildren (adjusted OR = 3·91, 95% CI 2·91, 5·27). There was no statistically significant difference in the likelihood of elevated MAP between the two fitness categories after adjusting for BMI only, BMI and sex, or BMI, sex, age and deprivation. How the likelihood of elevated MAP differed between BMI categories is shown in Table 3.

The results of the combined prediction of BMI category and fitness on elevated MAP are shown in Table 4. Fitness significantly attenuated the elevation of MAP associated with BMI categories. In Table 4, there was a difference in risk of elevated MAP within fitness and fatness categories: (i) obese-unfit, overweight-unfit and normal weight-unfit; (ii) obese-unfit, overweight-unfit and normal weight-fit; and almost in (iii) obese-unfit, overweight-unfit, obese-fit, overweight-fit, normal weight-unfit and normal weight-fit.

There was a clear trend towards elevated MAP in obese-fit participants compared with those who were normal weight but unfit (OR = 1·54, 95% CI 0·97, 2·45). Table 4 shows that obese-fit participants were more likely to have elevated MAP than those who were normal weight-fit (OR = 1·75, 95% CI 1·10, 2·79). These odds were not as pronounced as the increased likelihood of elevated MAP found in the obese-unfit group compared with the normal weight-fit group (OR = 3·98, 95% CI 2·92, 5·41). The likelihood of elevated MAP in normal weight-unfit participants was not significantly different from that in those who were normal weight-fit (OR = 0·87, 95% CI 0·67, 1·13).

Table 1 Baseline characteristics of the study participants in relation to their mean arterial pressure: schoolchildren (*n* 5983) aged 10–16 years, East of England, 2007–2009

	Frequency		SBP (mmHg)		DBP (mmHg)		MAP (mmHg)		MAP *Z*-score			Elevated MAP prevalence	
	n	%	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (difference in MAP *Z*-scores)	%	95 % CI (Fisher's exact)
Sex													
Female	2869	48·0	114·96	11·2	68·04	8·9	83·68	8·2	0·43	0·9	0·31	14·5	13·2, 16·8
Male	3114	52·0	116·26	12·1	66·01	9·0	82·76	8·3	0·45	0·8		15·2	14·0, 16·5
BMI (IOTF)†,‡													
Obese	313	5·3	119·32	11·9	70·45	9·0	86·72	8·1	0·82	0·8		29·7	24·7, 35·1
Overweight	1239	21·1	117·45	11·9	68·57	8·5	84·86	7·9	0·62	0·8	0·001	20·0	17·8, 22·4
Normal weight	4327	73·6	114·77	11·5	66·21	9·0	82·40	8·2	0·35	0·8		12·0	11·0, 13·0
Fitness													
Fit	4617	77·2	115·57	11·6	66·63	8·9	82·94	8·2	0·41	0·8	<0·001	13·9	12·9, 14·9
Unfit	1366	22·8	115·88	12·0	68·19	9·0	84·09	8·2	0·52	0·9		18·2	16·1, 20·3
Age (years)†													
10	270	4·5	111·09	11·0	66·44	10·1	81·33	9·0	0·42	1·0		16·7	12·4, 21·7
11	1097	18·3	112·81	10·8	66·09	9·0	81·66	8·0	0·38	0·9		12·3	10·4, 14·4
12	1749	29·2	114·05	11·7	66·12	9·2	82·10	8·5	0·37	0·9		13·3	11·8, 15·0
13	1337	22·3	116·82	11·5	67·79	8·6	84·13	7·8	0·51	0·8	<0·001	16·7	14·7, 18·8
14	980	16·4	117·96	11·6	67·98	8·8	84·64	8·1	0·48	0·8		16·7	14·5, 19·2
15	520	8·7	121·38	10·9	68·16	8·3	85·90	7·5	0·52	0·8		16·0	12·9, 19·4
16	30	0·5	124·90	11·2	66·13	9·7	85·72	8·4	0·38	0·8		16·7	5·6, 34·7
Obese-unfit	196	3·3	120·28	11·5	72·12	8·6	88·18	7·6	0·97	0·8		35·7	29·0, 42·9
Overweight-unfit	432	7·4	117·32	11·8	68·79	8·1	84·97	7·4	0·63	0·8		20·6	16·9, 24·7
Normal weight-unfit	702	11·9	113·55	11·8	66·46	9·2	82·16	8·3	0·31	0·8		10·8	8·6, 13·4
Obese-fit	117	2·0	117·70	12·5	67·58	9·0	84·29	8·3	0·56	0·8	<0·001	19·7	12·9, 28·0
Overweight-fit	805	13·7	117·49	11·9	68·44	8·7	84·79	8·2	0·62	0·8		19·6	16·9, 22·5
Normal weight-fit	3627	61·7	115·01	11·4	66·17	8·9	82·45	8·2	0·36	0·8		12·3	11·2, 13·4
Total	5983	100·0	115·64	11·7	66·98	9·0	83·20	8·3	0·44	0·8		14·8	14·0, 15·8

SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; IOTF, International Obesity Taskforce.
†*P* values of those variables with more than two groups (BMI and age) were derived from main effects, using ANOVA.
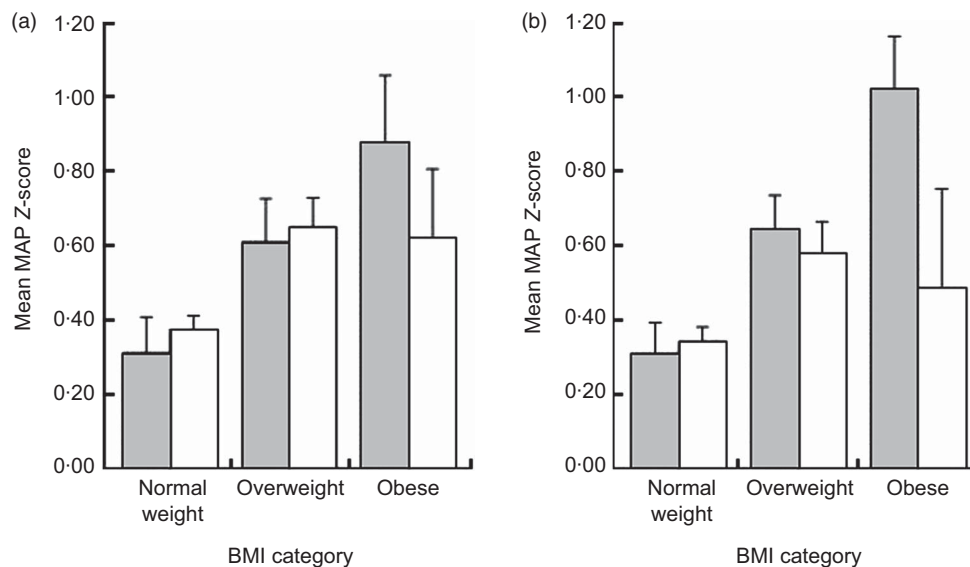‡BMI category missing for 104 participants (1·7 %).

Fig. 1 Variation in mean arterial pressure (MAP) according to BMI category (normal weight, overweight and obese, using International Obesity Taskforce cut-offs) and fitness status (▨, unfit; ☐, fit) among schoolchildren (*n* 5983) aged 10–16 years, East of England, 2007–2009: (a) females; (b) males. Values are means with 95 % confidence intervals represented by vertical bars

Table 2 Bonferroni tests for multiple comparisons of mean differences and 95 % confidence intervals of mean arterial pressure *Z*-scores among schoolchildren (*n* 5983) aged 10–16 years, East of England, 2007–2009

	MAP *Z*-score			
	Females		Males	
Multiple comparison	Mean difference	95 % CI	Mean difference	95 % CI
BMI (IOTF)†				
Normal weight *v.* overweight	−0·27**	−0·36, −0·18	−0·28**	−0·37, −0·19
Normal weight *v.* obese	−0·39**	−0·56, −0·22	−0·54**	−0·70, −0·38
Overweight *v.* obese	−0·12[NS]	−0·30, 0·07	−0·26**	−0·44, −0·09
Fitness‡				
Unfit *v.* fit	0·08[NS]	0·00, 0·16	0·15**	0·08, 0·22
Fitness in obese group‡				
Unfit *v.* fit	0·26[NS]	0·00, 0·52	0·54**	0·27, 0·82

MAP, mean arterial pressure; IOTF, International Obesity Taskforce.
**$P < 0·01$.
†BMI category missing for 104 participants (1·7 %).
‡Independent samples *t* test was used for this analysis (Bonferroni test is appropriate only with >3 fitness groups).

Discussion

BMI and cardiorespiratory fitness are both associated with BP in youth, but assessing the independence of this relationship has been hampered by methodological differences between studies. We hypothesized that cardiorespiratory fitness would attenuate the adverse association that overweight and obesity have with BP in youth when both independent variables were classified using evidence-based cut-off points related to adult health outcomes. The results indicated that adequate levels of cardiorespiratory fitness may favourably modify the weight-related elevations in MAP observed in obese/overweight schoolchildren. Fitness did not however appear to have a significant impact on BP in normal-weight schoolchildren. There was a dose–response association between higher BMI and

elevated MAP. Both overweight and obese schoolchildren who were fit had a reduced risk of elevated MAP than those of similar weight who were unfit.

MAP is derived from the combination of standard measures of SBP and DBP and is an important predictor of stroke[28,29]. MAP allows description of BP as a single measurement and is a robust tool suited to non-laboratory assessment protocols. We found similar results to those reported for MAP, when elevated (>91st centile) SBP and DBP were used as the outcome variable.

The prevalence of elevated MAP found in the present study is similar to that of others[30]. There are a number of previous studies which have tested the 'fit but fat' hypothesis[11,12,16,17], although the present study is the first one in English schoolchildren. To our knowledge, the present study is the first with a sufficient sample size

Table 3 Binary logistic regression output showing characteristics predicting elevated mean arterial pressure (>91st centile) among schoolchildren (*n* 5983) aged 10–16 years, East of England, 2007–2009

Predictor	Combined				Males				Females			
	Unadjusted OR	95 % CI	Adjusted OR†	95 % CI	Unadjusted OR	95 % CI	Adjusted OR	95 % CI	Unadjusted OR	95 % CI	Adjusted OR	95 % CI
BMI (IOTF)‡												
Obese	3·10§	2·39, 4·02	3·91§	2·91, 5·27	3·52§	2·51, 4·95	4·30§	2·89, 6·38	2·57§	1·72, 3·86	3·30§	2·09, 5·22
Overweight	1·84§	1·55, 2·17	1·97§	1·65, 2·36	1·63§	1·29, 2·05	1·77§	1·38, 2·28	2·07§	1·63, 2·64	2·19§	1·69, 2·84
Normal weight	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.
Fitness												
Unfit	1·38§	1·17, 1·62	1·02	0·84, 1·23	1·42§	1·15, 1·76	1·02	0·80, 1·30	1·29	1·00, 1·66	1·03	0·76, 1·39
Fit	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.
Sex												
Female	0·94	0·82, 1·09	0·94	0·81, 1·10	–	–	–	–	–	–	–	–
Male	1·00	Ref.	1·00	Ref.	–	–	–	–	–	–	–	–
Age (years)												
10	1·00	0·36, 2·75	0·82	0·30, 2·28	0·87	0·23, 3·27	0·72	0·19, 2·72	1·09	0·22, 5·37	0·85	0·17, 4·24
11	0·70	0·26, 1·86	0·63	0·23, 1·68	0·67	0·19, 2·37	0·62	0·17, 2·20	0·70	0·15, 3·32	0·58	0·12, 2·75
12	0·79	0·29, 2·03	0·71	0·27, 1·88	0·90	0·26, 3·15	0·89	0·25, 3·13	0·62	0·13, 2·92	0·50	0·10, 2·35
13	1·00	0·38, 2·64	1·05	0·39, 2·79	1·13	0·32, 3·94	1·18	0·34, 4·14	0·85	0·18, 3·99	0·82	0·17, 3·88
14	1·00	0·37, 2·66	1·06	0·40, 2·82	1·04	0·30, 3·63	1·12	0·32, 3·94	0·94	0·20, 4·44	0·90	0·19, 4·27
15	0·95	0·35, 2·55	0·83	0·31, 2·24	1·18	0·33, 4·19	1·02	0·28, 3·66	0·66	0·14, 3·22	0·53	0·11, 2·62
16	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.
Deprivation (quintile)												
1 (least deprived)	0·90	0·71, 1·13	0·94	0·75, 1·19	0·82	0·60, 1·12	0·86	0·62, 1·19	1·02	0·72, 1·44	1·11	0·77, 1·58
2	0·81	0·64, 1·02	0·83	0·66, 1·06	0·84	0·61, 1·15	0·84	0·61, 1·16	0·85	0·59, 1·20	0·85	0·59, 1·24
3	0·85	0·68, 1·08	0·84	0·66, 1·07	0·68§	0·49, 0·94	0·65§	0·46, 0·91	1·16	0·83, 1·62	1·17	0·82, 1·66
4	0·96	0·76, 1·21	0·95	0·75, 1·20	0·98	0·72, 1·32	0·93	0·68, 1·27	1·08	0·77, 1·51	1·05	0·74, 1·50
5 (most deprived)	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.	1·00	Ref.

IOTF, International Obesity Task Force; Ref., referent category.
†Adjusted model contains BMI, fitness, sex and age.
‡BMI category missing for 104 participants (1·7 %).
§Significantly different from the referent category.

Table 4 Odds ratios and 95 % confidence intervals of elevated mean arterial pressure (>91st centile) determined by the combined influence of BMI and cardiorespiratory fitness among schoolchildren (*n* 5983) aged 10–16 years, East of England, 2007–2009

Interaction term	Combined		Males		Females	
	OR	95 % CI	OR	95 % CI	OR	95 % CI
BMI (IOTF)† × fitness						
Obese × unfit	3·98‡	2·92, 5·41	4·28‡	2·90, 6·32	3·39‡	2·03, 5·67
Overweight × unfit	1·86‡	1·44, 2·39	1·70‡	1·22, 2·37	2·08‡	1·40, 3·10
Normal weight × unfit	0·87	0·67, 1·13	0·93	0·67, 1·28	0·75	0·49, 1·16
Obese × fit	1·75‡	1·10, 2·79	1·93	0·97, 3·82	1·64	0·87, 3·12
Overweight × fit	1·75‡	1·43, 2·14	1·54‡	1·15, 2·06	1·97‡	1·50, 2·60
Normal weight × fit	1·00	Ref.	1·00	Ref.	1·00	Ref.

IOTF, International Obesity Task Force; Ref., referent category.
†BMI category missing for 104 participants (1·7 %).
‡Significantly different from the referent category.

to utilize the IOTF classifications. Participants in the European Youth Heart Study (EYHS) differed in fitness and fatness according to country of residence (Denmark, Portugal, Estonia and Norway)[12]; such was the influence of country on CVD risk factors that, when added as a dummy variable to prediction models for BP, country had a greater influence than fitness. The participants in the current study had a higher prevalence of overweight, obesity and elevated BP than EYHS participants, due probably to our high inclusion rate and because English children tend to be fatter[31].

Fitness as an effect modifier

In males, BMI was significantly associated with MAP and there was a difference in mean MAP *Z*-score between normal-weight and obese boys. Fitness had no influence on BP in normal-weight or overweight boys, but those who were obese-fit had significantly lower MAP than those who were obese-unfit. A similar trend was evident in females; obese-unfit girls had higher MAP than obese-fit girls. When obese-fit and obese-unfit schoolchildren were compared with those who were normal weight-fit, there was a gradient in the prevalence of elevated MAP, with those who were obese-unfit having the highest prevalence of elevated MAP. The association between fatness and MAP was greatly modified by improving the specification of our regression model (including fitness and BMI interactions terms). In univariate regression analysis, fitness was a predictor of elevated MAP; however, fitness did not predict elevated MAP in a BMI-adjusted model.

Previous studies have found differences in CVD risk factors in the most 'extreme' groups, i.e. high fat/low fit *v.* low fat/high fit, and vice versa[18,32]. Differences within 'fatness' categories like those shown here, are less common. It may be the case that we have found such differences in the present study due to separating participants into three clinically relevant 'fatness' categories (normal weight, overweight and obese), while other studies have used only two fatness categories (high fat/low fat) based on arbitrary cut-off points like median split[15,18,32]. The present data suggest

a positive influence of fitness on MAP both in overweight and obese schoolchildren, which is more pronounced in the more markedly 'fat' (i.e. obese) when categorized using meaningful cut-off points. Our more rigorous methodology and use of agreed cut-off points have produced relatively novel findings with few comparable results from previous studies. For example, Eisenmann *et al.*[11] found differences in MAP according to fitness/fatness category in children classified according to fatness (percentage body fat using recognized cut-off points[33]) and fitness (estimated oxygen consumption). Due to relatively small sample size they[11] adjusted the fitness categories to ensure adequate participant numbers in each of the four fitness/fatness groups. Males with low fitness had significantly higher BP in those with high body fat compared with those with low body fat. Consistent with the present findings, high fitness was cardioprotective in girls with high body fat.

In the Quebec Family Study[18], 761 children were classified into four BMI and fitness groups using median split. The authors then compared several CVD risk factors between groups. In agreement with our findings, unfit males and females had higher MAP than their fit counterparts within BMI categories.

The Aerobics Centre Longitudinal Study[32] examined factors associated with the metabolic syndrome according to BMI category and fitness in 8–18-year-olds (*n* 484). In common with the present study, there were no differences in risk factors within the low BMI group according to fitness level but fitness did attenuate metabolic risk among overweight children and adolescents. Shaibi *et al.*[34] found univariate relationships between fitness and the metabolic syndrome in overweight youths, but these were non-significant after adjusting for fat mass. Like others[10], they concluded that the association between fitness and metabolic health was a function of body composition. Overall, it appears that fatness plays a greater role than fitness in determining MAP and other metabolic risk factors. There is, however, a growing body of evidence that fitness can significantly attenuate the elevations in MAP observed in fatter children. This may be more apparent when obese children are studied as a

distinct sub-sample as opposed to when a population is arbitrarily divided according to BMI.

The mechanisms linking BP with cardiorespiratory fitness in children are not fully understood. The benefits that cardiorespiratory fitness has on the vasculature are believed to be mediated by endothelial progenitor cells, which support vascular repair[35,36]. A healthy blood vessel requires an intact endothelium and a degree of elasticity. High fitness is associated with lower arterial stiffness and greater arterial compliance in children[37] and may decrease total resistance[38]. There is also evidence, however, that vascular changes in response to physical training may be transitory[39].

Given that the impact of interventions aimed at increasing physical activity on body composition has been negligible[40], it is important to note that obese schoolchildren may achieve significant health benefits by improving their fitness, regardless of their BMI.

A limitation of the current study is that we were unable to adjust for biological maturity of the participants as no measure was available. Likewise we could not adjust for other confounding variables like diet, family history of hypertension and smoking status, all of which may be associated with MAP in youth.

Our measures of oscillometric BP were made in the 'field' and are comparable with office assessments made by physicians. They should not be regarded as comparable with clinical measures capable of diagnosing paediatric hypertension. They remain useful for inter-individual comparisons within the population but comparisons with values from other studies using different techniques and devices should be made with caution.

The cross-sectional nature of the study design limits our ability to draw causal inferences and prospective studies are needed to solve the issue of temporality. Despite the large sample size, the use of IOTF categories and the relatively low prevalence of elevated MAP in certain subgroups may limit the robustness of some of the regression analyses.

Conclusions

The present study is the first to analyse the combined influence of fitness and fatness on BP in English schoolchildren. Due to the large cohort of schoolchildren, we were able to use internationally recognized cut-off points for fitness and BMI in order to create meaningful and clinically relevant categories, which are a major improvement over previous studies. Although the results do not entirely show that high fitness eliminates the presence of elevated BP associated with high BMI, they do show that fitness weakens the direct association between BMI and elevated BP. It appears, however, that this attenuation may be limited to schoolchildren who are obese. Hypertension is one of the most prevalent

co-morbidities associated with obesity in childhood[41]. Schoolchildren who are unfit and overweight or obese are at the highest risk of elevated BP. Given the stronger independent associations of simple objective measurements – cardiorespiratory fitness via field testing and BMI – with MAP, more emphasis should be placed on children's cardiorespiratory fitness and not only on BMI and weight reduction. The results suggest that obese individuals' MAP may be significantly improved by increasing fitness. Longitudinal studies are warranted to address the issue of temporality among these variables.

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