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**A five year longitudinal study investigating the prevalence of childhood obesity:  
comparison of BMI and waist circumference**

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## Abstract

**Objective:** The purpose of this study was to examine the prevalence of obesity over time in the same individuals comparing body mass index (BMI), waist circumference (WC) and waist to height ratio (WHtR).

**Study design:** Five year longitudinal repeated measures study (2005 – 2010). Children were aged 11-12 (Y7) years at baseline and measurements were repeated at age 13-14 (Y9) years and 15-16 (Y11) years.

**Methods:** WC and BMI measurements were carried out by the same person over the five years and raw values were expressed as standard deviation scores (sBMI and sWC) against the growth reference used for British children.

**Results:** Mean sWC measurements were higher than mean sBMI measurements for both sexes and at all assessment occasions and sWC measurements were consistently high in girls compared to boys. Y7 sWC = 0.792 [95% confidence interval (CI) 0.675–0.908], Y9 sWC = 0.818 (95%CI 0.709-0.928), Y11 sWC = 0.943 (95%CI 0.827-1.06) for boys; Y7 sWC = 0.843 (0.697-0.989), Y9 sWC = 1.52 (95%CI 1.38-0.67), Y11 sWC = 1.89 (95%CI 1.79-2.04) for girls. Y7 sBMI = 0.445 (95%CI 0.315-0.575), Y9 sBMI = 0.314 (95%CI 0.189-0.438), Y11 sBMI = 0.196 (95%CI 0.054-0.337) for boys; Y7 sBMI = 0.353 (0.227-0.479), Y9 sBMI = 0.343 (95%CI 0.208-0.478), Y11 sBMI = 0.256 (95%CI 0.102-0.409) for girls. The estimated prevalence of obesity defined by BMI decreased in boys (18%, 12% and 10% in Y 7, 9 and 11 respectively) and girls (14%, 15% and 11% in Y 7, 9 and 11). In contrast, the prevalence estimated by WC increased sharply (boys; 13%, 19% and 23%; girls, 20%, 46% and 60%).

**Conclusion:** Central adiposity, measured by WC is increasing alongside a stabilisation in BMI. Children appear to be getting fatter and the additional adiposity is being stored centrally which is not detected by BMI. These substantial increases in WC are a serious concern, especially in girls.

Children, obesity, central obesity, BMI, waist circumference, longitudinal

## Introduction

Childhood obesity has become a major public health concern. Obese children have an increased risk of developing health, psychological and social problems (1) and are more likely to be obese in adolescence and adulthood (2, 3). In addition to affecting personal health, the increased health risks translate into an increased burden on the health care system and the economy.

Recent publications from a number of countries (4), including the UK (5, 6), suggest there has been a levelling off in overweight and obesity prevalence occurring in the child population as a whole, or in certain subgroups of it. However, the most up to date cross-sectional prevalence data does not provide encouragement that public health targets aimed at reducing obesity can be met. On average, 13.3% and 14.6% of children in reception (aged 4-5) and year 6 (aged 11-12) respectively are overweight and a further 9.8% and 18.7% are obese (5).

A major concern with the current evidence base is that it relies solely on the use of BMI to determine obesity and is predominately cross-sectional. There is emerging evidence to suggest that central obesity is increasing at a faster rate than BMI (7-9) and concern should be raised in light of the increased health risks associated with central obesity in childhood (10-13). Furthermore, relying solely on cross-sectional prevalence data does not provide any insight on the duration of obesity.

This paper builds on the recently published, cross-sectional data from the Rugby League and Athletics Development Scheme (RADS) (6) comparing the prevalence of obesity estimated by three different measures of adiposity, body mass index (BMI), waist

circumference (WC) and waist-to-height-ratio (WHtR), using a longitudinal design over 5 years.

## **Methods and procedures**

The Rugby League and Athletics Development Scheme (RADS) is a collaboration between Leeds City Council (LCC), Leeds Metropolitan University and the Education Authority (Education Leeds - EL). Ethical clearance was granted by the Ethics Committee of the Carnegie Faculty, Leeds Metropolitan University.

Cross sectional data from the RADS programme has been reported previously (6). All secondary schools in Leeds were invited to take part in the programme which was aimed at children in their first year of secondary school (age 11-12 years). The purpose of the programme was to identify talented children who were not engaged in sport outside of school. All 33 schools that participated in the original cross sectional programme (6) were invited to participate in the follow up however, only 7 schools agreed to participate. Although the participation rate at a school level was lower than anticipated (7 from 33 schools), participation at an individual level (i.e. children from the 7 schools that participated in the longitudinal follow up) remained high in line with the cross sectional data collection (6) (> 90% at each measurement occasion in each of the 7 schools).

Data collection started in September 2005 when the children were in Y 7 (aged 11-12 years). Measurements were then repeated in January 2008 when the children were in Y9 (aged 13-14 years) and finally in January 2010 when the children were in Y11 (aged 15-16 years). Therefore, the time interval between measurements may vary slightly. All children consenting from the seven schools were eligible to take part, however, only children with at least 2 measurements were included in the analysis. In total 336 (45%) children had all

measurements from all three years of data collection (i.e. 'complete data' allowing a direct comparison of exactly the same pupils over all 3 assessment occasions). However an additional 410 (55%) children had at least two measurements (Y7 and Y9 n=254 (34%); Y7 and Y11 n=87 (12%); Y9 and Y11 n=69(9%)) resulting in 746 children used in the final analysis (i.e. mixed data). Sensitivity analysis showed that using just the complete data did not substantively alter overall conclusions.

Information on children who were not measured as part of the programme was not obtained. However, it should not be assumed that those not providing data opted out for example, children may have been absent from school on the testing day.

Due to the low numbers of children in ethnic groups other than White British it was not possible to allow comparisons between ethnic groups.

## Measures

Body mass was measured in kilograms (kg) using manually calibrated electronic scales (Tanita TBF-310 Tanita Corp., Tokyo, Japan). Children wore light indoor physical education clothing without shoes and were instructed to stand on the scales with their weight distributed evenly between both feet (14). Stature was measured to the nearest 0.1cm using a floor-standing Leicester height measure (model 220) (15). Waist circumference (WC) was measured mid-way between the 10<sup>th</sup> rib and the iliac crest (8, 16) in a horizontal (transverse) plane to the nearest 0.1 cm using an inelastic tape, with the children in a standing position wearing a thin t shirt. To allow for clothing 0.5cm was subtracted from the waist circumference measurement (8) and this resulting value is used in analyses. All testing took place on school premises and all measurements were carried out by the same person (CG).

BMI measurements were standardised (sBMI) for age and sex with the British 1990 growth reference charts (UK90) (17). WC measurements were standardised (sWC) for age and sex using the published reference based on the data from the British Standards Institute survey

(18). Standardised measurements were calculated using the conversion programme obtained from the Child Growth Foundation (19, 20) for the UK90 growth reference curves, which were designed so as to have a mean of zero and a standard deviation of 1 at each age. Waist-to-height ratio (WHtR) was calculated as WC (cm) / stature (cm). Children were classified as obese based on their sBMI and sWC to allow comparison while accounting for normal growth. The 95<sup>th</sup> reference centile (standardised score = 1.64) was used to define obesity for these two and a WHtR exceeding 0.5 was used to define obesity (12, 21).

### Statistical Analysis

The prevalence of obesity was calculated as a percentage of those exceeding the reference threshold and binary logistic, repeated measures Multi-Level Models (MLM) were used to investigate obesity prevalence over time using the MLwiN program (*MLwiN. Bristol. UK*). Measurement year (i.e. year 7, 9 and 11) was included at level 1 and pupils were included in the model at level 2. In multi-level structures balanced data are not required to obtain efficient estimates (22), i.e. with repeated measures it is not necessary to have the same number of measurement occasions (level 1) per individual (level 2). With MLM all of the available data can be incorporated into the analysis, thereby maximising the use of available data. Furthermore, MLM gives estimates of the variability of the level 2 units which can also depend on level 1 variables. The effect of the fixed effect predictors ( $B_0 - B_3$  in the model) were seen to be very similar when fitting models of the same form using Generalized Estimating Equations (GEEs) another technique for dealing with inherent clustering as in repeated measures within individuals, providing confidence in the results from this analysis.

The MLM were fitted used using Maximum Likelihood Estimation. Testing year was included as a discrete variable (0, 1, 2) for simplicity of reporting results. It was treated as a linear relationship. Comparison of the same models with testing year treated as a categorical

variable was considered and resulted in the same substantive overall conclusions. Gender was included in the model as an interaction term with testing year to investigate if its effect changes as the children get older. The alpha level adopted for statistical significance was  $p < 0.05$  i.e. absolute value of the coefficient if 1.96 times the SE.

## Results

Table 1 shows descriptive statistics for raw anthropometric measurements and the associated standardised BMI and WC measurements (sBMI and sWC respectively). Based on the fact that the children are growing, one would expect to observe significant increases in the mean of raw measurements. Mean sWC measurements are higher for both sexes than mean sBMI measurements and higher in girls compared to boys at all three assessment occasions, which is in agreement with recent published cross sectional data from the Health Survey for England (9)

The changes in the mean sWC for girls increased from the 79<sup>th</sup> centile (sd score = 0.84) of the reference population to the 97<sup>th</sup> (sd score = 1.89) centile between the ages of 11 – 16 years. Mean sWC for boys increased from the 78<sup>th</sup> (sd score = 0.79) centile of the reference population to the 82<sup>th</sup> (sd score = 0.94) centile between the ages of 11 – 16 years.

### Prevalence of obesity over time

Figure 1 shows the sample prevalence rates of obesity estimated by sBMI, sWC and WHtR for boys and girls separately. The three measures show considerably different patterns and there appears to be a difference between boys and girls. The estimated prevalence of obesity defined by sBMI is decreasing albeit it slightly, in boys (18%, 12% and 10% in year



7, 9 and 11 respectively) and girls (15%, 15% and 11% in year 7, 9 and 11). The prevalence estimated by sWC increases sharply between the measurement years. This pattern is supported by the results of MLM (table 2). The increase for girls is marked, such that by year 11 (aged 15-16 years) 60% of girls are obese by this measure, compared to 23% of boys. The prevalence of obesity estimated by WHtR lies between the estimates based on sWC and sBMI. However, the trends observed for boys and for girls are in different directions (i.e. the trend for boys is decreasing whilst that for girls increases).

Logistic multilevel models agree with the patterns observed (Table 2). The multilevel model included gender (reference = boy), and a testing year (linear) coefficient, and an interaction between testing year and gender. This enables a straight line over time logit prediction for boys and girls with different intercepts and different slopes. The prevalence of obesity estimated by sBMI is actually decreasing over time (per 2 school years between measurement points) (coefficient = -0.349 SE = 0.129) for boys but the additional increment of rate of change for girls is not significant (coefficient = 0.290 SE = 0.178). Obesity prevalence for boys estimated by sWC is significantly increasing over time (coefficient = 0.350 SE = 0.112) and the additional increase in girls is considerable (coefficient = 0.603 SE = 0.148). A flat trend is observed in the prevalence of obesity estimated by WHtR for boys (coefficient = -0.166 SE = 0.120) whereas for girls the additional increment shows an increasing trend (coefficient = 0.629 SE = 0.163).

## Discussion

Results show that the different measures of adiposity result in different findings, which is in agreement with cross sectional data (6, 8, 9). The prevalence of central obesity, measured by sWC is considerably higher than estimates based on sBMI and is increasing over time, especially in girls. Perhaps more importantly, this trend in sWC is observed alongside a

194 stabilisation in sBMI in the same children over the same time period. Large cross sectional  
195 studies (6, 8, 16) have previously shown that trends in WC greatly exceed those in BMI, in  
196 children. However, the RADS data is the first to investigate this important issue using a  
197 longitudinal design and it seems that the proportion of fat deposited centrally rather than  
198 peripherally is increasing as children get older, especially in girls.

199  
200 Furthermore, measured WC values from the RADS data at each centile, for both genders in  
201 all age groups, are considerably higher compared to the measured WC values from the  
202 reference data (18) see Table 3. The biggest shifts are observed in girls as they get older,  
203 which is supported by previous cross sectional data (8, 9, 16) and longitudinal data (7). What  
204 is perhaps more concerning from the comparisons in table 3 is that by age 14 almost 25% of  
205 the girls from the RADS data exceed adult cut points for increased risk (88cm) and 10%  
206 exceed adult cut points for obesity (88cm).

207  
208 Many studies of the change in the prevalence of obesity in children concentrate on BMI, in  
209 line with national recommendations (23). The longitudinal RADS data does offer some cause  
210 for optimism at the local level. The stabilisation observed based on sBMI is a rare piece of  
211 good news and supports numerous cross sectional publications (4, 6). However, we believe  
212 this is the most up to date data to compare obesity prevalence trends estimated by BMI, WC  
213 and WHtR in the same children from a longitudinal design and the results show that the  
214 increase in WC is substantial and is likely to be greater than that for BMI. Which is in  
215 agreement with cross sectional data from the Health Survey for England (9). Suggesting that  
216 relying on BMI as an estimate of obesity may not capture the real picture.

217  
218 From a public health perspective the stabilisation in general obesity estimated by sBMI could  
219 be viewed as promising, as efforts to tackle obesity may have resulted in an environment  
220 that is less permissive to obesity (although there are no formal evaluations to support this).

221 However, these longitudinal data place these 'positive' trends in a different light, because  
222 very few obese children actually lose weight to become a healthy weight between the ages  
223 of 11-16 years. This is even more worrying when sWC data is considered, as the prevalence  
224 of central obesity estimated by sWC actually continues to increase between childhood and  
225 adolescence, regardless of the observed stabilisation in sBMI. It seems that the  
226 contemporary obesity epidemic is characterised by an early onset and longer exposure to  
227 obesity than perhaps previously thought. Furthermore it seems that the additional adiposity  
228 is being stored centrally.

230 It is important to acknowledge that the three measures are looking at different aspects of  
231 obesity, which may in part explain the differences in the patterns observed. BMI is an indirect  
232 measure of general adiposity (it only measures stature and mass not adiposity directly),  
233 whereas WC is a surrogate measure of central adiposity, and when measured in conjunction  
234 with stature (WHtR) gives an index of proportionality. Research has demonstrated that WC  
235 offers no advantages over BMI in predicting general adiposity (or total body fat) (24, 25)  
236 however, WC has been shown to be superior to BMI in predicting central adiposity in  
237 children (13, 26). A major drawback of only considering total body fat (i.e. BMI) is that it  
238 gives no indication of body fat distribution, and it has been known for some time that a  
239 central distribution of body fat carries a higher risk for obesity related ill health in adults and  
240 children (27-31). BMI and WC interact in a complex fashion, especially during childhood and  
241 studies that have compared measures of adiposity, including this one, show that there is a  
242 wide variation in body fatness within subjects with the same BMI. Furthermore, this data  
243 suggests that changes in BMI (or general fatness) do not reflect changes in central adiposity.  
244 As separate measures of fatness BMI, WC and WHtR have been shown to perform well (32)  
245 however, as measures of risk they can lead to different interpretations. Conclusions linking  
246 BMI, WC and WHtR as measures of obesity to health risk cannot be drawn from this data.  
247 However, the findings do have implications for public health. Relying on BMI alone may

conceal differences in body composition, especially central adiposity, therefore provide inaccurate estimates of obesity prevalence and the associated health risks.

Although there is an emerging evidence base to suggest that central adiposity in children is more relevant to health outcomes than overall adiposity estimated by sBMI (10-12, 29-31, 33), it is not yet possible to estimate the impact of the increase in sWC on current and future morbidity, but such increases should be a cause for concern. Most shocking is the fact that by the time the children reach 15-16 years 25% of the girls exceed adult cut points (23) for overweight (80cm) and 10% actually exceed the adult cut points for obesity (88cm). This can be considered a robust finding given that these adult cut points have the most evidence in relation to future health risk (23). This would not have been detected by sBMI or WHtR prevalence estimates alone. Of the 25% of girls with a WC exceeding 80cm, 26% had a WHtR < 0.5 and 62% were not obese according to their sBMI. Likewise for those girls with a WC exceeding 88cm, 13% had a WHtR <0.5 and 32% were not obese according to their BMI. Closer monitoring of WC, particularly in longitudinal studies with long-term follow up of individuals, are required.

This study is not without limitations. Firstly, there is considerable concern with the use of standardised WC measurements in children, and so these findings should be interpreted in light of the potential limitations of the standardisation process for WC in children (18). The author of these charts (18) suggests that they should be validated against longitudinal data, because that they do not know if they accurately adjust for growth changes. One conclusion from these data may be that they do not. It is possible therefore that the prevalence figures (estimated by WC) shown in figure 1 are overestimated and so should be interpreted with caution. However, comparison of the actual measured WC values (i.e. not subject to the statistical draw backs of the standardisation process) from the RADS data and the reference data (table 3) support the overall findings, that WC is increasing as children get older and

275 this increase is marked in girls. Furthermore, cross sectional data report similar gender  
276 disparities (9).

277  
278 Secondly this study is based on one city in the north east of England and has a modest  
279 sample size over the five years and so is not generalizable to the population of England.  
280 However, the results are in agreement with National cross sectional data (9) which are  
281 generalisable to the general population of the UK.

282  
283 Finally, it would interesting to investigate the prevalence of obesity and the shift in BMI and  
284 WC distributions over the study period by ethnicity. Body composition, particularly visceral  
285 adiposity, varies by ethnicity and so this may affect the interpretation and this becomes of  
286 greater significance in adulthood.

## 287 288 289 Conclusion

290 Regardless of the measure used to determine obesity the proportion of obese children, has  
291 never been larger than it is today. Although the conclusion that childhood obesity prevalence  
292 estimated by sBMI is stable may be welcome news, the increase in WC and WHtR is a  
293 concern; incidence rate and duration of central obesity estimated by sWC are increasing  
294 alongside a stabilisation in sBMI. Children appear to be getting fatter with the additional  
295 adiposity being stored centrally, especially in girls. It is therefore possible that the health  
296 burden associated with obesity may be higher than expected, regardless of the observed  
297 stabilisation in prevalence estimated by sBMI.

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303

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402 Table 1. Mean (95% t - confidence intervals) anthropometric measurements at each measurement occasion

	Y7 (age 11-12)		Y9 (age 13-14)		Y11 (age 15 – 16)	
	Boy n=330	Girl n=347	Boy n= 331	Girl n=328	Boy n=252	girl n=239
Stature (cm)	148.1 (147.4 to 148.9)	149.2 (148.4 to 150.0)	164.5 (163.6 to 165.4)	160.3 (159.6 to 160.9)	174.2 (173.3 to 175.1)	164.3 (163.2 to 165.3)
Mass (kg)	n=317 41.6 (40.5 to 42.6)	n= 346 43.3 (42.3 to 44.4)	n=329 54.4 (53.2 to 55.7)	n=320 54.1 (52.8 to 55.4)	n=251 63.6 (62.2 to 65.1)	n=239 58.8 (57.3 to 60.3)
BMI (kg.m <sup>2</sup> )	n=317 18.8 (18.5 to 19.2)	n=346 19.3 (18.8 to 19.7)	n=329 20.0 (19.6 to 20.4)	n=320 20.9 (20.5 to 21.4)	n=251 20.9 (20.5 to 21.4)	n=239 21.7 (21.3 to 22.2)
sBMI	0.445 (0.315 to 0.575)	0.353 (0.227 to 0.479)	0.314 (0.189 to 0.438)	0.343 (0.208 to 0.478)	0.196 (0.0541 to 0.337)	0.256 (0.102 to 0.409)
WC (cm)	n=321 67.5 (66.5 to 68.5)	n=340 65.7 (64.8 to 66.6)	n=331 73.5 (72.5 to 74.5)	n=328 74.4 (73.2 to 75.6)	n=252 79.0 (77.9 to 80.1)	n=238 78.2 (76.9 to 79.3)
sWC	0.792 (0.675 to 0.908)	0.843 (0.697 to 0.989)	0.818 (0.709 to 0.928)	1.52 (1.38 to 1.67)	0.943 (0.827 to 1.06)	1.89 (1.79 to 2.04)
WHtR	n=321 0.456 (0.449 to 0.462)	n=340 0.440 (0.435 to 0.446)	n=331 0.447 (0.441 to 0.453)	n=328 0.464 (0.457 to 0.471)	n=251 0.453 (0.447 to 0.459)	n=238 0.476 (0.469 to 0.483)

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Table 2. Coefficients (SE) from multilevel logistic models considering the prevalence of obesity over time (reference = boy)

		sBMI	sWC	WHtR
<b>Fixed part</b>				
B <sub>0</sub>	Reference (boy, year7[intercept])	-1.533(0.168)*	-1.864(0.158)*	-1.562(0.154)*
B <sub>1</sub>	Gender (girl)	-0.195(0.237)	0.576(0.206)	-0.137(0.216)
B <sub>2</sub>	Occasion (increment for boys)	-0.349(0.129)*	0.350(0.112)*	-0.166(0.120)
B <sub>3</sub>	Gender_Occasion (increment for girls)	0.290(0.178)	0.603(0.148)*	0.629(0.160)*
<b>Random part</b>				
	Variance ( u <sub>0j</sub> )	3.074(0.337)*	1.257(0.185)*	1.690(0.231)*
	Units (pupils)	741	742	742
	Units (year)	1802	1810	1809

$$\text{logit (obese)} = \beta_0 + \beta_1 (\text{girl}) + \beta_2 (\text{occassion}) + \beta_3 (\text{girl.equation})$$

B = the change in the outcome for a one unit change in the predictor (for logistic regression B equals the change in the logit of the outcome variable associated with one unit change in predictor variable); SE = standard error; \* significant at  $p < 0.05$

Table 3. Comparison of RADS centiles data to McCarthy et al (2001) data for measured WC (cm)

			centiles						
Age			5 <sup>th</sup>	10 <sup>th</sup>	25 <sup>th</sup>	50 <sup>th</sup>	75 <sup>th</sup>	90 <sup>th</sup>	95 <sup>th</sup>
11-12 years	Boys	RADS	56.4	57.5	60.5	65.5	71.5	80.5	85.5
		McCarthy	51.9	53.6	56.6	60.2	64.1	67.9	70.4
	Girls	RADS	54.5	56.5	59.5	64.5	71.5	79.5	84.5
		McCarthy	52.0	53.2	55.4	58.2	61.1	65.4	68.1
13-14 years	Boys	RADS	60.7	63.5	66.5	72.0	77.5	84.5	91.9
		McCarthy	54.8	56.9	60.4	64.6	69.0	73.1	75.5
	Girls	RADS	60.2	62.5	65.5	72.0	81.0	91.0	99.1
		McCarthy	55.3	56.4	58.7	61.7	65.3	69.1	71.8
15-16 years	Boys	RADS	68.1	69.8	73.5	77.4	83.8	89.5	97.1
		McCarthy	59.0	61.1	64.8	69.3	74.2	79.0	82.0
	Girls	RADS	64.5	68.1	72.2	76.5	82.7	91.5	99.5
		McCarthy	57.6	58.9	61.3	64.4	67.9	71.7	74.3

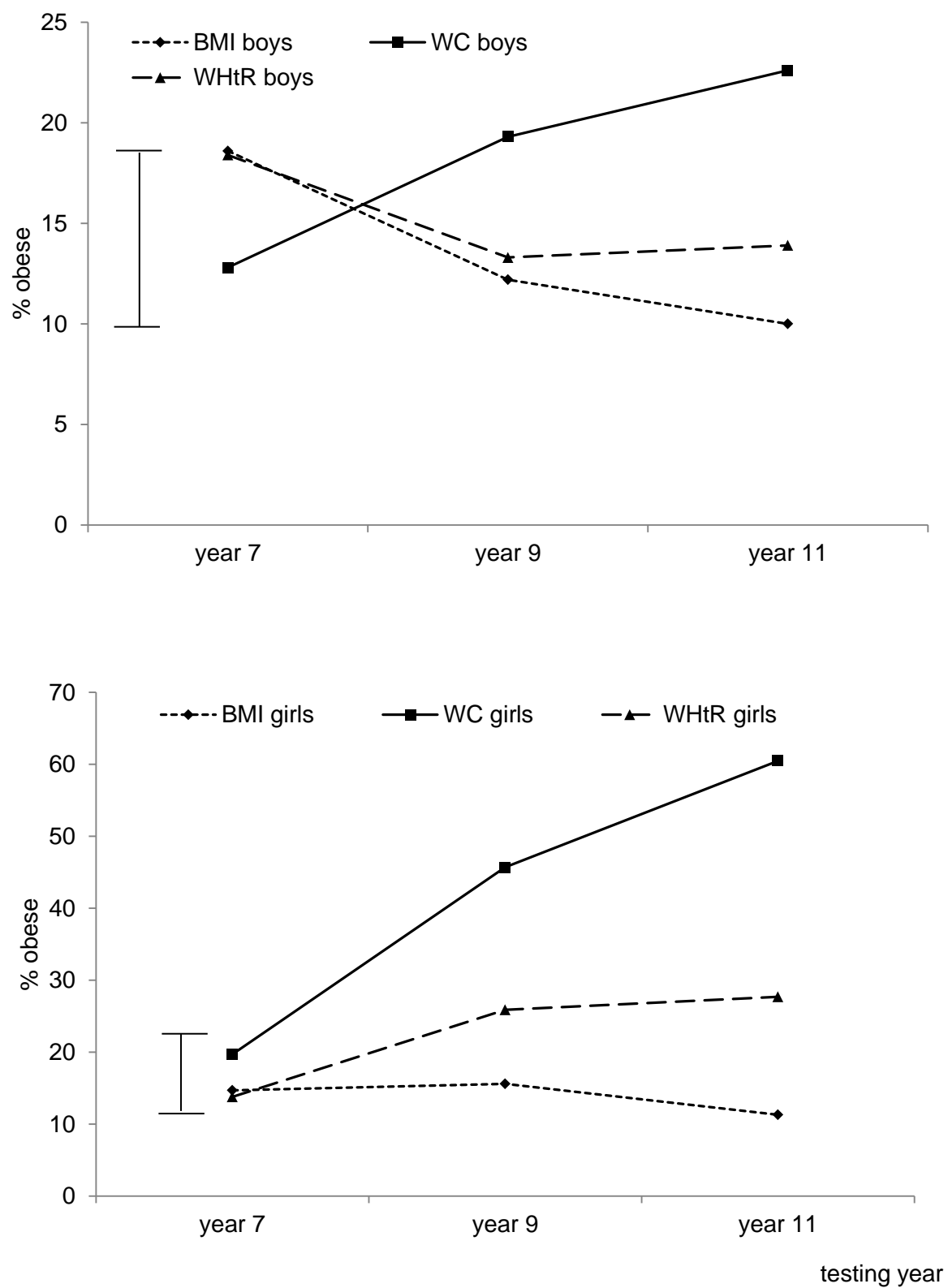


Figure 1. Prevalence of obesity measured by BMI, WC and WHtR over time in boys (top) and girls (bottom) [Black vertical lines represents approximate 95% confidence interval for the increase in prevalence over time]