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Citation:

Griffiths, C and Gately, P and Marchant, PR and Cooke, CB (2013) A five year longitudinal study investigating the prevalence of childhood obesity: comparison of BMI and waist circumference. *Public health*, 127 (12). 1090 - 1096. ISSN 0033-3506 DOI: <https://doi.org/10.1016/j.puhe.2013.09.020>

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

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8 Abstract

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

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

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

18 **Results:** Mean sWC measurements were higher than mean sBMI measurements for both
19 sexes and at all assessment occasions and sWC measurements were consistently high in
20 girls compared to boys. Y7 sWC = 0.792 [95% confidence interval (CI) 0.675–0.908], Y9
21 sWC = 0.818 (95%CI 0.709-0.928), Y11 sWC = 0.943 (95%CI 0.827-1.06) for boys; Y7 sWC
22 = 0.843 (0.697-0.989), Y9 sWC = 1.52 (95%CI 1.38-0.67), Y11 sWC = 1.89 (95%CI 1.79-
23 2.04) for girls. Y7 sBMI = 0.445 (95%CI 0.315-0.575), Y9 sBMI = 0.314 (95%CI 0.189-
24 0.438), Y11 sBMI = 0.196 (95%CI 0.054-0.337) for boys; Y7 sBMI = 0.353 (0.227-0.479), Y9
25 sBMI = 0.343 (95%CI 0.208-0.478), Y11 sBMI = 0.256 (95%CI 0.102-0.409) for girls. The
26 estimated prevalence of obesity defined by BMI decreased in boys (18%, 12% and 10% in Y
27 7, 9 and 11 respectively) and girls (14%, 15% and 11% in Y 7, 9 and 11). In contrast, the
28 prevalence estimated by WC increased sharply (boys; 13%, 19% and 23%; girls, 20%, 46%
29 and 60%).

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

34

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

36 **Introduction**

37

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

43

44 Recent publications from a number of countries (4), including the UK (5, 6), suggest there
45 has been a levelling off in overweight and obesity prevalence occurring in the child
46 population as a whole, or in certain subgroups of it. However, the most up to date cross-
47 sectional prevalence data does not provide encouragement that public health targets aimed
48 at reducing obesity can be met. On average, 13.3% and 14.6% of children in reception (aged
49 4-5) and year 6 (aged 11-12) respectively are overweight and a further 9.8% and 18.7% are
50 obese (5).

51

52 A major concern with the current evidence base is that it relies solely on the use of BMI to
53 determine obesity and is predominately cross-sectional. There is emerging evidence to
54 suggest that central obesity is increasing at a faster rate than BMI (7-9) and concern should
55 be raised in light of the increased health risks associated with central obesity in childhood
56 (10-13). Furthermore, relying solely on cross-sectional prevalence data does not provide any
57 insight on the duration of obesity.

58

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

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

64

65 **Methods and procedures**

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

70

71 Cross sectional data from the RADS programme has been reported previously (6). All
72 secondary schools in Leeds were invited to take part in the programme which was aimed at
73 children in their first year of secondary school (age 11-12 years). The purpose of the
74 programme was to identify talented children who were not engaged in sport outside of
75 school. All 33 schools that participated in the original cross sectional programme (6) were
76 invited to participate in the follow up however, only 7 schools agreed to participate. Although
77 the participation rate at a school level was lower than anticipated (7 from 33 schools),
78 participation at an individual level (i.e. children from the 7 schools that participated in the
79 longitudinal follow up) remained high in line with the cross sectional data collection (6) (>
80 90% at each measurement occasion in each of the 7 schools).

81

82 Data collection started in September 2005 when the children were in Y 7 (aged 11-12 years).
83 Measurements were then repeated in January 2008 when the children were in Y9 (aged 13-
84 14 years) and finally in January 2010 when the children were in Y11 (aged 15-16 years).
85 Therefore, the time interval between measurements may vary slightly. All children
86 consenting from the seven schools were eligible to take part, however, only children with at
87 least 2 measurements were included in the analysis. In total 336 (45%) children had all

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

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

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

99

100 Measures

101

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

112

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

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

123

124 Statistical Analysis

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

138

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

142 variable was considered and resulted in the same substantive overall conclusions. Gender
143 was included in the model as an interaction term with testing year to investigate if its effect
144 changes as the children get older. The alpha level adopted for statistical significance was p
145 < 0.05 i.e. absolute value of the coefficient if 1.96 times the SE.

146

147 **Results**

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

155

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

160

161 Prevalence of obesity over time

162

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

167 7, 9 and 11 respectively) and girls (15%, 15% and 11% in year 7, 9 and 11). The prevalence
168 estimated by sWC increases sharply between the measurement years. This pattern is
169 supported by the results of MLM (table 2). The increase for girls is marked, such that by year
170 11 (aged 15-16 years) 60% of girls are obese by this measure, compared to 23% of boys.
171 The prevalence of obesity estimated by WHtR lies between the estimates based on sWC
172 and sBMI. However, the trends observed for boys and for girls are in different directions (i.e.
173 the trend for boys is decreasing whilst that for girls increases).

174

175 Logistic multilevel models agree with the patterns observed (Table 2). The multilevel model
176 included gender (reference = boy), and a testing year (linear) coefficient, and an interaction
177 between testing year and gender. This enables a straight line over time logit prediction for
178 boys and girls with different intercepts and different slopes. The prevalence of obesity
179 estimated by sBMI is actually decreasing over time (per 2 school years between
180 measurement points) (coefficient = -0.349 SE = 0.129) for boys but the additional increment
181 of rate of change for girls is not significant (coefficient = 0.290 SE = 0.178). Obesity
182 prevalence for boys estimated by sWC is significantly increasing over time (coefficient =
183 0.350 SE = 0.112) and the additional increase in girls is considerable (coefficient = 0.603 SE
184 = 0.148). A flat trend is observed in the prevalence of obesity estimated by WHtR for boys
185 (coefficient = -0.166 SE = 0.120) whereas for girls the additional increment shows an
186 increasing trend (coefficient = 0.629 SE = 0.163).

187

188 **Discussion**

189

190 Results show that the different measures of adiposity result in different findings, which is in
191 agreement with cross sectional data (6, 8, 9). The prevalence of central obesity, measured
192 by sWC is considerably higher than estimates based on sBMI and is increasing over time,
193 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.

229

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

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

250

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

264

265 This study is not without limitations. Firstly, there is considerable concern with the use of
266 standardised WC measurements in children, and so these findings should be interpreted in
267 light of the potential limitations of the standardisation process for WC in children (18). The
268 author of these charts (18) suggests that they should be validated against longitudinal data,
269 because that they do not know if they accurately adjust for growth changes. One conclusion
270 from these data may be that they do not. It is possible therefore that the prevalence figures
271 (estimated by WC) shown in figure 1 are overestimated and so should be interpreted with
272 caution. However, comparison of the actual measured WC values (i.e. not subject to the
273 statistical draw backs of the standardisation process) from the RADS data and the reference
274 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.

298 Acknowledgement

299 We would like to thank Leeds City Council and Carnegie Weight Management for their initial
300 collaboration in establishing the programme. In addition we would like to thank Leeds City
301 Council and the secondary schools that participated in the programme for providing the data
302 from the rugby league and athletics development scheme (RADS).

303

304 Funding – None

305 Competing interests – none declared

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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)	41.6 (40.5 to 42.6)	43.3 (42.3 to 44.4)	54.4 (53.2 to 55.7)	54.1 (52.8 to 55.4)	63.6 (62.2 to 65.1)	58.8 (57.3 to 60.3)
BMI (kg.m ²)	18.8 (18.5 to 19.2)	19.3 (18.8 to 19.7)	20.0 (19.6 to 20.4)	20.9 (20.5 to 21.4)	20.9 (20.5 to 21.4)	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)	67.5 (66.5 to 68.5)	65.7 (64.8 to 66.6)	73.5 (72.5 to 74.5)	74.4 (73.2 to 75.6)	79.0 (77.9 to 80.1)	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	0.456 (0.449 to 0.462)	0.440 (0.435 to 0.446)	0.447 (0.441 to 0.453)	0.464 (0.457 to 0.471)	0.453 (0.447 to 0.459)	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
Fixed part			
B ₀ Reference (boy, year7[intercept])	-1.533(0.168)*	-1.864(0.158)*	-1.562(0.154)*
B ₁ Gender (girl)	-0.195(0.237)	0.576(0.206)	-0.137(0.216)
B ₂ Occasion (increment for boys)	-0.349(0.129)*	0.350(0.112)*	-0.166(0.120)
B ₃ Gender_Occasion (increment for girls)	0.290(0.178)	0.603(0.148)*	0.629(0.160)*
Random part			
Variance (u _{0j})	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 th	10 th	25 th	50 th	75 th	90 th	95 th
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

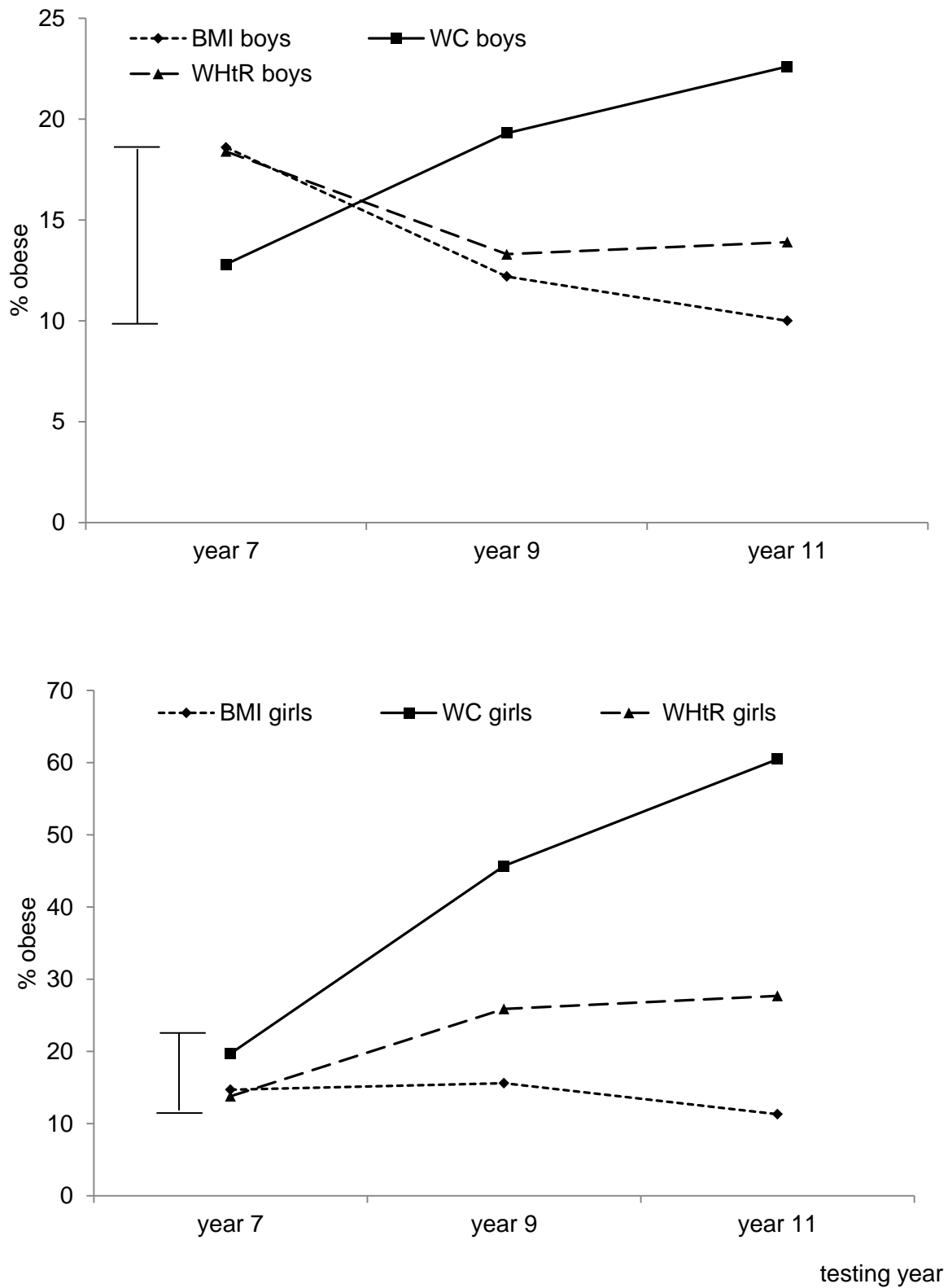


Figure 1. Prevalence of obesity measured by BMI, WC and WHtR over time in boys (top) and girls (bottom) [Black vertical lines represents approximate 95% confidence interval for the increase in prevalence over time]