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Assessing the impact of adjusting for maturity in children's weight status classification in a cohort of UK children

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ABSTRACT

Objectives To compare the weight categorisation of a cohort of UK children using standard procedures (i.e., comparing BMI percentiles to age-matched UK reference data) versus an approach adjusted for maturation status (i.e., matching relative to biological age).

Design Analysis of data collected from an observational study of UK primary school children.

Setting Schools in south west England.

Participants Four hundred and seven 9-11 year old children (Mean age 10.88 years, SD=0.46, range 9-11; 98% white British)

Main outcome measures: Weight status was classified using BMI percentiles using (i) sex and chronological-age matched referents, and (i) sex and biological-age matched referents (based on % of predicted adult stature) relative to UK 1990 reference growth charts. Using both approaches, children were classified as a normal weight if >2nd percentile and <85th percentile, overweight if 85th and <95th percentiles, and obese if ≥95th percentile.

Results Fifty-one children (12.5%) were overweight, and a further 51 obese (12.5%) according to standard chronological-age matched classifications. Adjustment for maturity resulted in 32% of overweight girls, and 15% of overweight boys being reclassified as a normal weight, and 11% and 8% of obese girls and boys respectively being reclassified as overweight. Early maturing children were 4.9 times more likely to be reclassified from overweight to normal weight than ‘on-time’ maturers (odds ratio 95% CI=1.3 to 19.0).

Conclusions: Incorporating assessments of maturational status into weight classification resulted in significant changes to the classification of early-maturing adolescents. Further work to explore the implications for objective health risk is needed.

ARTICLE SUMMARY

Strengths and Limitations of this study

- The analyses are based on objective height and weight measurements of 407 children taken by trained researchers implementing a rigorous protocol.
- The approach is the first to demonstrate a simple, readily replicable means of exploring or adjusting for the impact of maturity timing on weight categorisation during adolescence.
- While the sample was representative of the diversity of children in one geographical area of the UK, the data are not nationally representative and ethnic minority groups are particularly under-represented.

INTRODUCTION

As a means of identifying children at elevated risk of poor health and wellbeing, the classification of children's weight status is widely practiced by physicians and public health teams in many countries.[1-3] Yet, parents' recognition of when a child is overweight can be as low as 25%.[4] This is in part exacerbated by the normalisation of overweight now that approximately 33% of UK 10-11 year olds are overweight or obese. Schemes such as England's National Child Measurement Programme (NCMP), through which over 95% of 4-5 and 10-11 year old children are weighed each year,[5] provide excellent data for monitoring population-level obesity. However, the NCMP has also been used to provide objective feedback to parents on their child's weight status with a view to improving awareness and engaging families with weight management services. To date however, providing NCMP data as feedback has resulted in little uptake of weight management support,[6] and may have alienated many parents who are angry and/or disbelieving of the information provided.[6-8]

Research investigating the source of parental anger and rejection of the weighing and measuring of children highlights that many parents fear that the risk of harm to their child's health and wellbeing is greater from *labelling* them as overweight (e.g., in undermining self-esteem and triggering eating disorder symptomology and poor self-esteem) than it is from *being* overweight.[6-10] In the absence of conclusive evidence that this is not the case, and given that strong negative associations between parent-child weight talk and well-being have been reported,[11] health professionals have a responsibility to ensure that any intervention that could incur such risks is based on accurate information and does not target those for whom it may not be necessary.

A primary reason that parents offer for being distrusting of the information provided about their child's weight status is that such judgements fail to account for individual differences. In particular, parents argue that when children approach puberty, judgements of their weight status that do not take account of relative differences in pubertal development are not valid[7]. The use of BMI for establishing weight status in relation to health risk in children is certainly problematic, especially during the period of peak growth velocity (average onset 11.8 in girls, and 14 in boys)[12] when height (and therefore the height to weight ratio on which the BMI is based) is liable to considerable change. Past work using Dual Energy X-ray Absorption scans to provide accurate assessments of body fat demonstrate a considerable normative increase in fat mass around the trunk in both boys and girls in the lead up to the period of peak height velocity (i.e., the main event referred to as 'puberty') regardless of physical activity and dietary fat intake.[13,14] Yet, these studies have not used data to adjust estimates of a child's weight status according to their maturity status.

There is currently no research reporting on whether adjustment for pubertal status would result in different classification of risk for children who are advanced in maturity. Despite this lack of work, it would is readily possible to do so within a practice setting via using non-invasive means of estimating children's maturity status that are currently available. Accordingly, the aim of this study is to investigate the degree to which the weight categorisation of a cohort of UK 9-11 year old children differs when estimated through comparison of their BMI against chronological age- and sex-matched UK BMI reference charts (standard UK practice), versus when estimated using reference charts matched to their biological (i.e., maturity adjusted) age. This analysis is undertaken with a view to providing a means of adjusting for expected maturity-related increases in body fat mass among children and adolescents to provide more accurate estimates of obesity prevalence. The process of generating more tailored estimates of weight status may also help to engage parents in discussions about a healthy weight for their child and has the potential to increase acceptance that a child is overweight.

METHODS

Participants

Participants were 407 9-11 year old children who formed the UK sample of the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE).[15] Participants were recruited from 26 primary schools in south west England. Schools were stratified according to student socio-economic status (SES; based on levels of entitlement to free school meals; high, mid, low) of the catchment area and weighted by size (large, small), and then approached sequentially to maximise the diversity of the sample of participating children. All year 6 children in participating schools were eligible to take part.

Procedure

Detailed information of the standardised data collection protocol is published elsewhere[15]. Written consent for the study was obtained from head teachers and parents, and assent provided by children prior to participation. A battery of anthropometric measurements were taken by staff trained in the ISCOLE protocol. Standing height was measured to the nearest 0.1 cm without shoes with the participant's head in the Frankfort Plane and at the end of a deep inhalation using a Seca 213 portable stadiometer (Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using a portable Tanita SC- 240 Body Composition Analyzer (Arlington Heights, IL). Subsequently, Body Mass Index (BMI; body mass (kg)/height (m^2)) was calculated. Overarching ethical approval for the ISCOLE protocol was provided by the Pennington Biomedical Research Center Institutional Review Board, and local ethical approval was also obtained for the UK site by the institutional research ethics committee. Data were entered into a secure central web-based management system, audited by the ISCOLE coordinating centre.

Classification of maturity and weight status. Maturity status was calculated by a non-invasive means (i.e., the Kamis-Roche method),[16] based on the percentage of predicted adult stature that a child had attained at measurement. This method holds that among youth of the same age, individuals who are closer to their mature (i.e., adult) stature are more advanced in biological maturity. A boy of 12 years who has attained 90% of predicted adult height, for example, would be considered more mature than a boy, of the same age and height, who had obtained 80% predicted adult height. The Khamis-Roche method predicts adult height from the child's age, height, and weight, and mid-height of the biological parents. Self-reported parent heights were adjusted for over-estimation using equations generated from over 1000 measured and self-estimated heights from adults.[17] The Khamis-Roche method has been validated against skeletal age in American youth[18] and has also been applied in studies of British youth.[19-21] The median error bounds between actual and predicted adult stature between the ages of 9 to 12 fall between 2.0 and 2.5 cm in boys, and 1.9 and 2.1 cm in girls, respectively.[16]

Maturity status was calculated using z-scores for the percentage of mature height achieved: for group comparisons, z-scores between -1.0 and + 1.0 were considered 'on time', z-scores below -1.0 'late maturers', and z-scores above 1.0, 'early maturers'.[22] To obtain an estimate of biological age, percentage of adult stature was compared with age and sex specific reference standards generated from the UK 1990 growth reference data.[23] Reference standards for percentage of adult stature attained were calculated at intervals of 0.1 years for each sex. Percentages were based upon mean values for stature attained at each age interval, and the mean values for stature attained at and above 18 years of age (177.6 cm in males; 163.7 cm in females). For example, a girl of 10.5 years who had attained 91.5% of predicted adult stature would have presented a value equivalent to the mean percentage of adult stature attained by UK girls aged 12.0 years. Accordingly, she would be assigned a maturational (biological) age of 12.0 years. For both standard and adjusted calculations of weight status, and in line with UK clinical practice, overweight and obesity was judged through reference to the UK1990 BMI reference data.[24] Children with a BMI ≥ the 85th percentile and <95th percentile were classified as overweight, and children over the 95th percentile as obese. The difference between the two classification systems (i.e., standard, and maturity adjusted) stemmed from the reference curve against which the child's BMI was compared. To calculate standard classifications, children were matched to the reference curve appropriate to their sex and chronological age in months. Each child's predicted adult stature was used to calculate maturity-adjusted classifications, providing an estimate of their biological age (i.e., that is the age at which they would be expected to achieve their current % adult stature according to UK reference growth charts). The child's BMI was then judged against the 85th and 95th percentiles for their biological age in line with the threshold used for population assessment using NCMP data by Public Health England (PHE) in 2016.[25]

Analysis

We examined whether the classification of weight differed significantly when using standard versus adjusted BMI percentiles using chi-square tests, and explored whether there were differences in the number of children reclassified according to sex or maturity status using ANOVA. Odds ratios of the probability of change in classification were calculated for early, on-time, and late maturers.

RESULTS

The sample comprised 407 children (78% of the 525 involved in the study; 223 girls (55%), Mean age 10.88 years, SD=0.46, range 9.3 -11.8) whose height and weight were objectively measured and whose biological parents self-reported their own heights. Average BMI was 18.34 (SD=2.95), and according to usual age and sex matched cut-offs, 51 (12.5%) children were classified as overweight, and a further 51 (12.5%) obese. Slightly more girls than boys were overweight or obese (26% versus 24%, respectively). No children were underweight (BMI < 2nd percentile). As expected, girls had reached a more advanced stage of maturity on average than boys (girls averaged 88% expected adult height, vs 81% for boys). Five percent of boys and 9% of girls were late maturers, 71% of boys and 61% of girls on-time, and 24% of boys and 30% of girls were early maturers.

The results of a 2-way (gender and weight status) ANOVA indicated that children were significantly more likely to be classified as overweight or obese if they were biologically more mature ($F(5, 401)=150.75$, $p<.001$; η^2 for maturity status=0.16). This was the case for both boys and girls (η^2 for sex=0.65), although it was more pronounced in girls (interaction term; $F(2,401)=5.47$, $p=0.005$; $\eta^2=0.03$) (Figure 1).

Figure 1: Trends in maturation status across weight categorisation

<Figure 1 here>

Comparisons with adjusted values

For the sample as a whole, the mean difference between chronological age and biological age (i.e., age for the given percentage of expected adult height achieved) was 0.18 years (SD = 0.46), ranging from a delay of 1.67 years, to being advanced by 5.5 years. This latter value relates to a girl with a height of 166.35 cm, who had reached 99.9% of her predicted adult height; her weight status did not change when adjusting for developmental stage (she was classified as obese using both systems).

When BMI percentile was adjusted for maturation, there was a small decrease in the proportion of children classified as overweight (from 12.5 to 10.6%), and obese (from 12.5% to 11.8%). This related to a small but significant decrease in the mean estimated BMI percentile within the sample; standard vs adjusted calculation Mean BMI = 58.15 (SD=30.06) vs 57.42 (SD=28.78) ($t(406)=3.09$, $p=.002$; $d=0.02$). Overall, 5 (11%) overweight or obese boys, and 13 (22%) of overweight or obese girls were reclassified into a lower weight category (Chi square = 582.72, $p<0.001$, Table 1). Only one boy and three girls were reclassified into a higher weight category.

Of the 111 children judged to be early maturers, 59% were classified as a healthy weight using standard chronological age growth reference charts (19% overweight, and 23% obese), compared with 67% following adjustment for maturity (13% overweight and 21% obese). Overweight early maturers (i.e., those we consider most important to 'get right' on the basis of requiring intervention or not) were 4.9 times more likely to be reclassified as a normal weight following maturity adjustment than their overweight on-time peers (43% vs 13%; odds ratio = 4.85; 95% CI 1.25 to 19.03). There was no apparent difference for obese children reclassified as overweight (8% vs 12%; odds ratio = 0.67, 95% CI 0.10 to 4.37).

Table 1: Comparison of weight classifications following BMI percentile adjustment

	Adjusted percentiles			
Standard percentiles	Healthy weight n(%)	Overweight n(%)	Obese n(%)	Total N
Boys	Chi-square (df=4) = 298.6, p<0.001			
Healthy weight	139 (>99)	1 (<1)	0	142
Overweight	3 (15)	17 (85)	0	20
Obese	0	2(8)	22 (92)	24
Girls	Chi-square (df=4) = 290.32, p<0.001			
Healthy weight	164 (>99)	1 (<1)	0	165
Overweight	10 (32)	19 (61)	2 (7)	31
Obese	0	3 (11)	24 (89)	27

DISCUSSION

A comparison of the weight status categorisation of a sample of 9-11 year old UK children according to standard chronological age versus biological age growth charts resulted in the downward-classification of 18% of overweight and obese children, representing 22% of overweight girls and 11% of overweight boys. Only four children (1%) were reclassified into a higher weight category. This effect was more pronounced in girls, for whom almost one in three girls who were reported to be overweight would not have been classified as such using a maturity-adjusted approach. Given the limited age range of the sample, and that boys mature on average two years later than girls, the effect may reach a similar extent for boys but at a later age.

This is the first study to quantify the difference that adjusting judgements of weight status by a child's level of maturity could have on both population estimates of childhood overweight and obesity, and on the treatment of individual children and families. Its strengths lie in basing the analysis on a broad cohort of children using robust objective measurement protocols at an age when the effects of puberty are first starting to emerge, and importantly at the age when weight measurement by health professionals takes place and the lack of consideration for maturity is known to be a source of tension between parents and health services. A limitation of the study is that the original UK 1990 dataset bases the norms on which the BMI percentiles that we (and health services) use include children of all maturity levels, not only on-time maturers. However, it is likely that the differences observed in our analyses would have been greater, rather than smaller, if the reference data had also standardised for maturity status (i.e., if off-time maturers could be removed).

BMI is acknowledged to be a useful but imperfect proxy indicator of fat mass (and excess fat mass) and subsequent health risk.[26-28] While past work has explored how moderating factors such as sex, race and ethnicity[29,30] may influence the accuracy of BMI in predicting health risk, we are not aware of any research that has explored the effects of biological maturity in children and adolescents. The analyses presented here illustrate the difference in weight classification that would result from accounting for children's maturity status in addition to age and sex in benchmarking BMI against growth reference charts for the first time. As the healthy range for BMI increases with age up to adulthood as a reflection of expected healthy increases in body fat during puberty, it is likely that early maturing adolescents can be a normal or healthy weight at a higher BMI than their later maturing peers: however, research specifically mapping maturity-adjusted weight categorisation to health risk is needed to formally test this hypothesis.

These findings post two key implications for practice: First, they raise the question of whether we should adjust for maturity when judging whether children or adolescents are overweight. Given the lack of evidence that weight monitoring (as undertaken through the NCMP and similar programmes) results in positive effects on children's health and health behaviours,[6,31] and some evidence that such monitoring activities could undermine their wellbeing and self-concept,[7,8] there seems little risk that doing so will result in harm (children not identified, and not receiving help). Whereas the practice could be of benefit if by tailoring for maturity in line with parent requests, we are better able to raise awareness and engage with parents whose children remain classified as overweight or obese following adjustment. Second, the findings suggest that early maturing children are particularly at risk of misclassification; this group are already known to be at greater risk of poor mental health[32-34] and may be particularly susceptible to the negative impact of such evaluations as they generally hold more negative perceptions of the physical self (lower perceptions of attractiveness, sports competence, and fitness.[35] As such, early maturing adolescents represent a vulnerable group with whom we should be particularly careful to minimise the potential unintended negative consequences of health policies.

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Competing interests:

None to declare

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Details of contributors

Fiona Gillison led in the drafting of the paper, development of the idea for the use of the ISCOLE data in this way (with SC), conduct of analyses (with CB). She was a CI for the UK ISCOLE site, involved with data collection, researcher training and quality oversight.

Sean Cumming provided expertise in the assessment of maturity and interpretation of findings, contributed to the development of the concept for using the ISCOLE data in this way (with FG), and contributed to the drafting of the paper. He was involved with data collection and coordination for the UK ISCOLE site.

Martyn Standage is the PI of the UK ISCOLE study site, and contributed to the drafting of the paper.

Catherine Barnaby provided input and expertise to the analysis of the study data and contributed to the drafting of the paper.

Peter Katzmarzyk is the PI of ISCOLE across the 12-centre site, responsible for the design of the original study and oversight of data collection and analysis, and contributed to drafting the paper.

We confirm that all authors had access to all of the data and can take responsibility for the integrity of the data and accuracy of the data analysis.

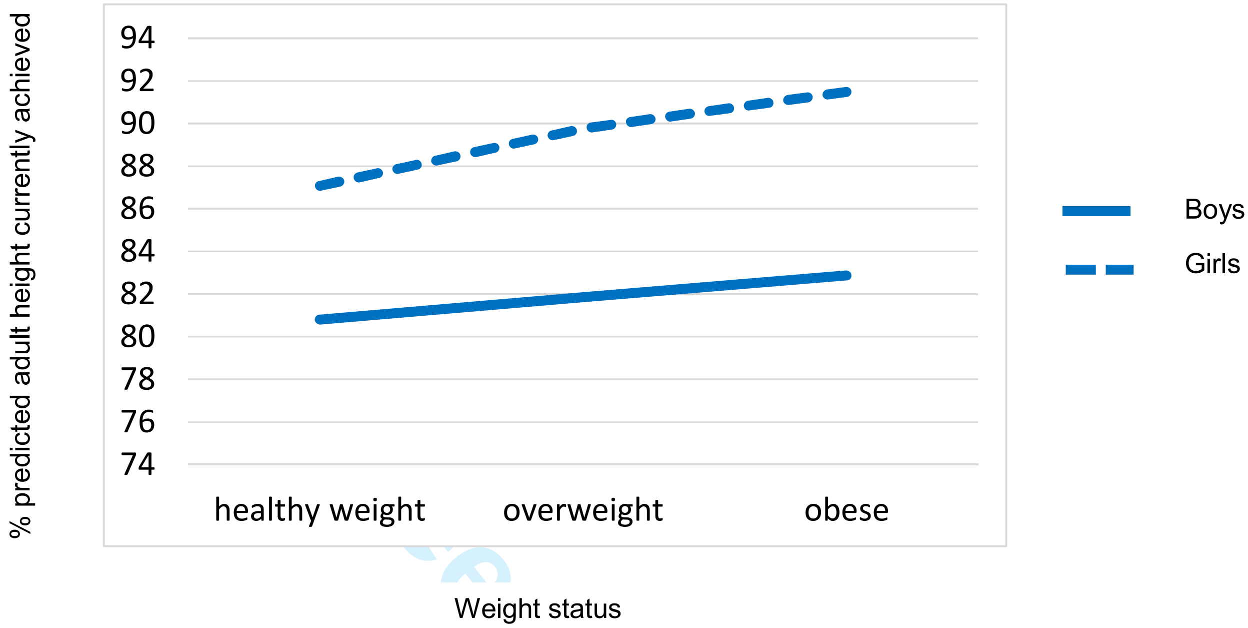
Data sharing statement

Data sharing: no additional data available.

URL to study protocol:

http://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-13-900

Figure 1: Trends in maturation status across weight categorisation



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Main outcome measures: Weight status was classified using BMI centiles using (i) sex and chronological-age matched referents, and (ii) sex and biological-age matched referents (based on % of predicted adult stature) relative to UK 1990 reference growth charts. For both approaches, children were classified as a normal weight if >2nd centile and <85th centile, overweight if 85th and <95th centiles, and obese if ≥95th centile.

Results Fifty-one children (12.5%) were overweight, and a further 51 obese (12.5%) according to standard chronological-age matched classifications. Adjustment for maturity resulted in 32% of overweight girls, and 15% of overweight boys being reclassified as a normal weight, and 11% and 8% of obese girls and boys respectively being reclassified as overweight. Early maturing children were 4.9 times more likely to be reclassified from overweight to normal weight than 'on-time' maturers (odds ratio 95% CI=1.3 to 19).

Conclusions: Incorporating assessments of maturational status into weight classification resulted in significant changes to the classification of early-maturing adolescents. Further research exploring the implications for objective health risk and wellbeing is needed.

ARTICLE SUMMARY

Strengths and Limitations of this study

- The analyses are based on objective height and weight measurements of 407 children taken by trained researchers implementing a rigorous standardised protocol.
- The approach is the first to demonstrate a simple and readily replicable means of exploring or adjusting for the impact of maturity timing on weight categorisation during late childhood /early adolescence.
- Although the sample was representative of the diversity of children in one geographical area of the UK, the data are not nationally representative and ethnic minority groups are particularly under-represented.

INTRODUCTION

Childhood obesity is consistently linked to a greater risk of obesity in adulthood and the consequent increased risk to health through conditions such as diabetes, cardiovascular disease, and certain forms of cancer.[1] As a means of identifying children at elevated risk, the classification of children's weight status is widely practised by physicians and public health teams in many countries.[2-4] Yet, parents' recognition of when a child is overweight can be as low as 25%.[5] This is in part exacerbated by the normalisation of being overweight, with approximately 33% of UK 10-11 year olds now being classified as overweight or obese. Schemes such as England's National Child Measurement Programme (NCMP), through which over 95% of 4-5 and 10-11 year old children are weighed each year,[6] provide excellent data for monitoring population-level obesity. However, the NCMP has also been used to provide objective feedback to parents on their child's weight status with a view to improving awareness and engaging families with weight management services. To date however, providing NCMP data as feedback has resulted in little uptake of weight management support,[7] and may have alienated many parents who are angry and/or disbelieving of the information provided.[7-9]

Research investigating the source of parental anger and rejection of the weighing and measuring of children highlights that many parents fear that the risk of harm to their child's health and wellbeing is greater from *labelling* them as overweight (e.g., in undermining self-esteem and triggering eating disorder symptomology and poor self-esteem) than it is from *being* overweight.[7-11] In the absence of conclusive evidence that this is not the case, and given that strong negative associations between parent-child weight talk and well-being have been reported,[12] health professionals have a responsibility to ensure that any intervention that could incur such risks is based on accurate information and does not target those for whom it may not be necessary.

A primary reason that parents offer for being distrusting of the information provided about their child's weight status is that such judgements fail to account for individual differences. In particular, parents argue that when children approach puberty, judgements of their weight status that do not take account of relative differences in pubertal development are not valid.[8] While there is reliable evidence that earlier puberty is associated with a greater risk of obesity, and thus that the two may be somewhat conflated,[13] researchers have also raised the question of whether it is appropriate to judge weight status based on BMI during puberty when some increase in body fat is normal and healthy.[14,15] The use of BMI for establishing weight status in relation to health risk in children is certainly problematic, especially during the period of peak growth velocity (average onset 11.8 years in girls, and 14.0 years in boys)[16] when height (and therefore the weight to height ratio on which the BMI is based) is liable to considerable change. Past work using Dual Energy X-ray Absorption scans to provide accurate assessments of body fat demonstrate a considerable normative increase in fat mass around the trunk in both boys and girls in the lead up to the period of peak height velocity (i.e., the main event referred to as 'puberty') regardless of physical activity and dietary fat intake.[17,18] Yet, these studies have not used data to adjust estimates of a child's weight status according to their maturity status.

There is currently no research reporting on the effect that adjustment for pubertal status could have on population estimates of obesity, or of how we could adjust the classification of risk for children who are advanced in maturity through acceptable, non-invasive means. Despite this lack of work, it would be possible to do so within a practice setting via using non-invasive means of estimating children's maturity status that are currently available. Accordingly, the aim of this study is to investigate the degree to which the weight categorisation of a cohort of UK 9-11 year old children differs when estimated through comparison of their BMI against chronological age- and sex-matched UK BMI reference charts (standard UK practice), versus when estimated using reference charts matched to their biological (i.e., maturity adjusted) age. This analysis is undertaken with a view to providing a means of adjusting for expected maturity-related increases in body fat mass among children and adolescents to provide more accurate estimates of obesity prevalence. The process of generating more tailored estimates of weight status may also help to engage parents in discussions about a healthy weight for their child and has the potential to increase acceptance that a child is overweight.

METHODS

Participants

Participants were 407 9-11 year old children who formed the UK sample of the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE).[19] Participants were recruited from 26 primary schools in south west England. Schools were stratified according to pupils socio-economic status (SES; based on levels of entitlement to free school meals; high, mid, low) of the catchment area and weighted by size (large, small), and then approached sequentially to maximise the diversity of the sample of participating children. All Year 6 children in participating schools were eligible to take part. The analytical sample used in this study showed little ethnic diversity, 98% were white British, compared with 90-97% in the local authorities were data were collected, and 87% nationally.

Procedure

Detailed information of the standardised data collection protocol is published elsewhere.[19] Written consent for the study was obtained from head teachers and parents, and assent provided by children prior to participation. A battery of anthropometric measurements were taken by staff trained in the ISCOLE protocol. Standing height was measured to the nearest 0.1 cm without shoes with the participant's head in the Frankfort Plane and at the end of a deep inhalation using a Seca 213 portable stadiometer (Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using a portable Tanita SC- 240 Body Composition Analyzer (Arlington Heights, IL). Subsequently, Body Mass Index (BMI; body mass (kg)/height (m^2)) was calculated. Overarching ethical approval for the ISCOLE protocol was provided by the Pennington Biomedical Research Center Institutional Review Board, and local ethical approval was also obtained for the UK site by the institutional research ethics committee. Data were entered into a secure central web-based management system, audited by the ISCOLE coordinating centre.

Classification of maturity and weight status. Maturity status was calculated by a non-invasive means (i.e., the Kamis-Roche method),[20] based on the percentage of predicted adult stature that a child had attained at measurement. This method holds that among youth of the same age, individuals who are closer to their mature (i.e., adult) stature are more advanced in biological maturity. A boy of 12 years who has attained 90% of predicted adult height, for example, would be considered more mature than a boy, of the same age and height, who had obtained 80% predicted adult height. The Khamis-Roche method predicts adult height from the child's age, height, and weight, and mid-height of the biological parents. Self-reported parent heights were adjusted for over-estimation using equations generated from over 1000 measured and self-estimated heights from adults.[21] The Khamis-Roche method has been validated against skeletal age in American youth[22] and has also been applied in studies of British youth.[23-25] The median error bounds (i.e. the confidence interval within which 50% of the cases for true height will fall) between actual and predicted adult stature between the ages of 9 to 12 fall between 2.0 and 2.5 cm in boys, and 1.9 and 2.1 cm in girls, respectively.[20]

Maturity status was calculated using z-scores for the percentage of mature height achieved: for group comparisons, z-scores between -1.0 and + 1.0 were considered 'on time', z-scores below -1.0 'late maturers', and z-scores above 1.0, 'early maturers'.[26] To obtain an estimate of biological age, percentage of adult stature was compared with age and sex specific reference standards generated from the UK 1990 growth reference data.[27] Reference standards for percentage of adult stature attained were calculated at intervals of 0.1 years for each sex. Percentages were based upon mean values for stature attained at each age interval, and the mean values for stature attained at and above 18 years of age (177.6 cm in males; 163.7 cm in females). For example, a girl of 10.5 years who had attained 91.5% of predicted adult stature would have presented a value equivalent to the mean percentage of adult stature attained by UK girls aged 12.0 years. Accordingly, she would be assigned a maturational (biological) age of 12.0 years. For both standard and adjusted calculations of weight status, and in line with the threshold used for population assessment using NCMP data by Public Health England in 2016,[28] overweight and obesity was judged through reference to the UK1990 BMI reference data.[29] Children with a BMI ≥ the 85th centile and <95th centile were classified as overweight, and children over the 95th centile as obese. The difference between the two classification systems (i.e., standard, and maturity adjusted) stemmed from the reference curve against which the child's BMI was compared. To calculate standard classifications, children were matched to the reference curve appropriate to their sex and chronological age in months.

Analysis

We examined whether the classification of weight differed significantly when using standard versus adjusted BMI centiles using chi-square tests, and explored whether there were differences in the number of children reclassified according to sex or maturity status using ANOVA. Effect sizes were also computed to provide an indication of the meaningfulness of statistical differences; η^2 indicates the effect size of F statistics in ANOVA; values ≥ 0.022 are considered a small but meaningful effect, ≥ 0.059 a moderate effect and 0.14 and upwards a large effect.[30] Cohen's d for 2-way comparisons (≥ 0.2 and ≤0.5 considered a small effect, ≥0.5 and ≤0.8 a moderate effect, and ≥0.8 a large effect). Odds ratios of the probability of change in classification were calculated for early, on-time, and late maturers.

RESULTS

The sample comprised 407 children (78% of the 525 involved in the study; 223 girls (55%), Mean age 10.9 years, SD=0.5, range 9.3 -11.8) whose height and weight were objectively measured and whose biological parents self-reported their own heights. Average BMI was 18.3 (SD=3.0), and according to usual age and sex matched cut-offs, 51 (12.5%) children were classified as overweight, and a further 51 (12.5%) obese. Slightly more girls than boys were overweight or obese (26% versus 24%, respectively). No children were underweight

(BMI < 2nd centile). On average, girls had reached a more advanced stage of maturity than boys (girls averaged 88% expected adult height, vs 81% for boys). Five percent of boys and 9% of girls were late maturers, 71% of boys and 61% of girls on-time, and 24% of boys and 30% of girls were early maturers.

The results of a 2-way (gender and weight status) ANOVA indicated that children were significantly more likely to be classified as overweight or obese if they were biologically more mature ($F(5, 401)=150$, $p<.001$; η^2 for maturity status=0.16). This was the case for both boys and girls (η^2 for sex=0.65), although it was more pronounced in girls (interaction term; $F(2,401)=5.5$, $p=0.005$; $\eta^2=0.03$) (Figure 1).

Figure 1: Trends in maturation status across weight categorisation
<Figure 1 here>

Comparisons with adjusted values

For the sample as a whole, the mean difference between chronological age and biological age (i.e., age for the given percentage of expected adult height achieved) was 0.18 years (SD = 0.6), ranging from a delay of 1.67 years, to being advanced by 5.5 years. This latter value refers to a girl with a height of 166cm, who had reached 99.9% of her predicted adult height; her weight status did not change when adjusting for developmental stage (she was classified as obese using both systems).

When BMI centile was adjusted for maturation, there was a small decrease in the proportion of children classified as overweight (from 12.5 to 10.6%), and obese (from 12.5% to 11.8%). This related to a small but significant decrease in the mean estimated BMI centile within the sample; standard vs adjusted calculation Mean BMI = 58.2 (SD=30.1) vs 57.4 (SD=28.8) ($t(406)=3.09$, $p=.002$; $d=0.02$). Overall, 5 (11%) overweight or obese boys, and 13 (22%) of overweight or obese girls were reclassified into a lower weight category (Chi square = 583, $p<0.001$, Table 1). Only one boy and three girls were reclassified into a higher weight category.

Of the 111 children judged to be early maturers, 59% were classified as a healthy weight using standard chronological age growth reference charts (19% overweight, and 23% obese), compared with 67% following adjustment for maturity (13% overweight and 21% obese). Overweight early maturers (i.e., those we consider most important to 'get right' on the basis of requiring intervention or not) were 4.9 times more likely to be reclassified as a normal weight following maturity adjustment than their overweight on-time peers (43% vs 13%; odds ratio = 4.9; 95% CI 1.25 to 19). There was no apparent difference for obese children reclassified as overweight (8% vs 12%; odds ratio = 0.67, 95% CI: 0.10 to 4.4).

Table 1: Comparison of weight classifications following BMI centile adjustment

	Adjusted centiles			
Standard centiles	Healthy weight n(%)	Overweight n(%)	Obese n(%)	Total N
Boys	Chi-square (df=4) = 299, p<0.001			
Healthy weight	139 (>99)	1 (<1)	0	142
Overweight	3 (15)	17 (85)	0	20
Obese	0	2(8)	22 (92)	24
Girls	Chi-square (df=4) = 290, p<0.001			
Healthy weight	164 (>99)	1 (<1)	0	165
Overweight	10 (32)	19 (61)	2 (7)	31
Obese	0	3 (11)	24 (89)	27

DISCUSSION

A comparison of the weight status categorisation of a sample of 9-11 year old UK children according to standard chronological age versus biological age growth charts resulted in the downward-classification of 18% of overweight and obese children, representing 22% of overweight girls and 11% of overweight boys. Only four children (1%) were reclassified into a higher weight category. This effect was more pronounced in girls, for whom almost one in three girls who were reported to be overweight would not have been classified as such using a maturity-adjusted approach. Given the limited age range of the sample, and that boys mature on average two years later than girls, the effect may reach a similar extent for boys but at a later age.

Within this study, we attempted to quantify the difference that adjusting judgements of weight status by a child's level of maturity could have on both population estimates of childhood overweight and obesity, and on the treatment of individual children and families. The strengths of work reside with basing the analysis on a broad cohort of children using robust objective measurement protocols at an age when the effects of puberty are first starting to emerge, and importantly at the age when weight measurement by health professionals takes place and the lack of consideration for maturity is known to be a source of tension between parents and health services. A limitation of this study is that the original UK 1990 dataset bases the norms on which the BMI centiles that we (and health services) use include children of all maturity levels, not only on-time maturers. However, it is likely that the differences observed in our analyses would have been greater, rather than smaller, if the reference data had also standardised for maturity status (i.e., if off-time maturers could be removed). We also note that children from ethnic minorities were under-represented in our sample.

BMI is acknowledged to be a useful but imperfect proxy indicator of fat mass (and excess fat mass) and subsequent health risk.[31-33] Past work has explored how moderating factors such as sex, race and ethnicity may influence the accuracy of BMI in predicting health risk,[34,35] however whereas the impact of puberty on BMI at a given chronological age is well established, few studies have attempted to quantify the impact of biological maturity has on the accuracy of weight classifications.[36] A sensitivity and specificity analysis of BMI in classifying obesity (as measured by body fat mass established through DXA scans, establishing puberty through tanner scales) in adolescents of all ages in New Zealand reported 6-12% of misclassification [36]. Nonetheless, the present study is the first to demonstrate how weight classification may account for children's maturity status in addition to age and sex when benchmarking BMI against growth reference charts, and to report on the likely effects (in terms of changes to weight classifications) of doing so. As the healthy range for BMI increases with age up to adulthood as a reflection of expected healthy increases in body fat during puberty, it is likely that early maturing children and adolescents can be a normal or healthy weight at a higher BMI than their later maturing peers: however, research specifically mapping maturity-adjusted weight categorisation to health risk is needed to formally test this hypothesis.

These findings post two key implications for practice. First, they raise the question of whether we should adjust for maturity when judging whether children or adolescents are overweight. Given the lack of evidence that weight monitoring (as undertaken through the NCMP and similar programmes) results in positive effects on children's health and health behaviours,[7,37] and some evidence that such monitoring activities could undermine their wellbeing and self-concept,[8,9] there seems little risk that adjusting for biological maturity will result in harm (i.e., children are not identified, and do not receive effective help). Whereas the practice could be of benefit if we are better able to raise awareness and engage with parents whose children remain classified as overweight or obese following adjustment as a result of showing that we have tailored the judgement to their child's level of biological maturity. Second, the findings suggest that early maturing children are particularly at risk of misclassification; this group are already known to be at greater risk of poor mental health[38-40] and may be particularly susceptible to the negative impact of such evaluations as they generally hold more negative perceptions of the physical self (lower perceptions of attractiveness, sports competence, and fitness.[41] As such, early maturing children and adolescents represent a vulnerable group with whom we should be particularly careful to minimise the potential unintended negative consequences of health policies.

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Competing interests:

None to declare

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Details of contributors

Fiona Gillison led in the drafting of the paper, development of the idea for the use of the ISCOLE data in this way (with SC), conduct of analyses (with CB). She was a CI for the UK ISCOLE site, involved with data collection, researcher training and quality oversight.

Sean Cumming provided expertise in the assessment of maturity and interpretation of findings, contributed to the development of the concept for using the ISCOLE data in this way (with FG), and contributed to the drafting of the paper. He was involved with data collection and coordination for the UK ISCOLE site.

Martyn Standage is the PI of the UK ISCOLE study site, and contributed to the drafting of the paper.

Catherine Barnaby provided input and expertise to the analysis of the study data and contributed to the drafting of the paper.

Peter Katzmarzyk is the PI of ISCOLE across the 12-country sites, responsible for the design of the original study and oversight of data collection and analysis, and contributed to drafting the paper.

We confirm that all authors had access to all of the data and can take responsibility for the integrity of the data and accuracy of the data analysis.

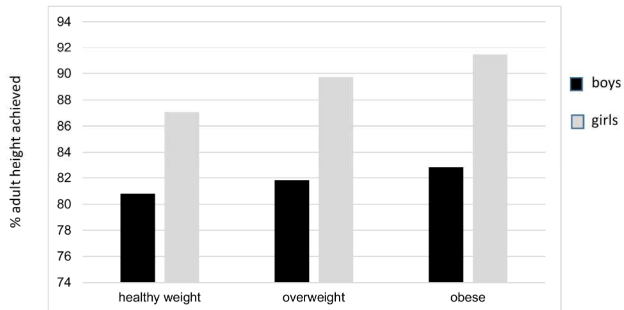
Data sharing statement

Data sharing: no additional data available.

URL to study protocol:

http://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-13-900

Figure 1: Trends in maturation status across weight categorisation



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Assessing the impact of adjusting for maturity in weight status classification in a cross-sectional sample of UK children

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Assessing the impact of adjusting for maturity in weight status classification in a cross-sectional sample of UK children

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ABSTRACT

Objectives To compare the weight categorisation of a cohort of UK children using standard procedures (i.e., comparing BMI centiles to age-matched UK reference data) versus an approach adjusted for maturation status (i.e., matching relative to biological age).

Design Analysis of data collected from an observational study of UK primary school children.

Setting Schools in south west England.

Participants Four hundred and seven 9-11 year old children (98% white British)

Main outcome measures: Weight status was classified using BMI centiles using (i) sex and chronological-age matched referents, and (ii) sex and biological-age matched referents (based on % of predicted adult stature) relative to UK 1990 reference growth charts. For both approaches, children were classified as a normal weight if >2nd centile and <85th centile, overweight if 85th and <95th centiles, and obese if ≥95th centile.

Results Fifty-one children (12.5%) were overweight, and a further 51 obese (12.5%) according to standard chronological-age matched classifications. Adjustment for maturity resulted in 32% of overweight girls, and 15% of overweight boys being reclassified as a normal weight, and 11% and 8% of obese girls and boys respectively being reclassified as overweight. Early maturing children were 4.9 times more likely to be reclassified from overweight to normal weight than 'on-time' maturers (odds ratio 95% CI=1.3 to 19).

Conclusions: Incorporating assessments of maturational status into weight classification resulted in significant changes to the classification of early-maturing adolescents. Further research exploring the implications for objective health risk and wellbeing is needed.

ARTICLE SUMMARY

Strengths and Limitations of this study

- The analyses are based on objective height and weight measurements of 407 children taken by trained researchers implementing a rigorous standardised protocol.
- The approach is the first to demonstrate a simple and readily replicable means of exploring or adjusting for the impact of maturity timing on weight categorisation during late childhood /early adolescence.
- Although the sample was representative of the diversity of children in one geographical area of the UK, the data are not nationally representative and ethnic minority groups are particularly under-represented.

INTRODUCTION

Childhood obesity is consistently linked to a greater risk of obesity in adulthood and the consequent increased risk to health through conditions such as diabetes, cardiovascular disease, and certain forms of cancer.[1] As a means of identifying children at elevated risk, the classification of children's weight status is widely practised by physicians and public health teams in many countries.[2-4] Yet, parents' recognition of when a child is overweight can be as low as 25%.[5] This is in part exacerbated by the normalisation of being overweight, with approximately 33% of UK 10-11 year olds now being classified as overweight or obese. Schemes such as England's National Child Measurement Programme (NCMP), through which over 95% of 4-5 and 10-11 year old children are weighed each year,[6] provide excellent data for monitoring population-level obesity. However, the NCMP has also been used to provide objective feedback to parents on their child's weight status with a view to improving awareness and engaging families with weight management services. To date however, providing NCMP data as feedback has resulted in little uptake of weight management support,[7] and may have alienated many parents who are angry and/or disbelieving of the information provided.[7-9]

Research investigating the source of parental anger and rejection of the weighing and measuring of children highlights that many parents fear that the risk of harm to their child's health and wellbeing is greater from *labelling* them as overweight (e.g., in undermining self-esteem and triggering eating disorder symptomology and poor self-esteem) than it is from *being* overweight.[7-11] In the absence of conclusive evidence that this is not the case, and given that strong negative associations between parent-child weight talk and well-being have been reported,[12] health professionals have a responsibility to ensure that any intervention that could incur such risks is based on accurate information and does not target those for whom it may not be necessary.

A primary reason that parents offer for being distrusting of the information provided about their child's weight status is that such judgements fail to account for individual differences. In particular, parents argue that when children approach puberty, judgements of their weight status that do not take account of relative differences in pubertal development are not valid.[8] While there is reliable evidence that earlier puberty is associated with a greater risk of obesity, and thus that the two may be somewhat conflated,[13] researchers have also raised the question of whether it is appropriate to judge weight status based on BMI during puberty when some increase in body fat is normal and healthy.[14,15] The use of BMI for establishing weight status in relation to health risk in children is certainly problematic, especially during the period of peak growth velocity (average onset 11.8 years in girls, and 14.0 years in boys)[16] when height (and therefore the weight to height ratio on which the BMI is based) is liable to considerable change. Past work using Dual Energy X-ray Absorption scans to provide accurate assessments of body fat demonstrate a considerable normative increase in fat mass around the trunk in both boys and girls in the lead up to the period of peak height velocity (i.e., the main event referred to as 'puberty') regardless of physical activity and dietary fat intake.[17,18] Yet, these studies have not used data to adjust estimates of a child's weight status according to their maturity status.

There is currently no research reporting on the effect that adjustment for pubertal status could have on population estimates of obesity, or of how we could adjust the classification of risk for children who are advanced in maturity through acceptable, non-invasive means. Despite this lack of work, it would be possible to do so within a practice setting via using non-invasive means of estimating children's maturity status that are currently available. Accordingly, the aim of this study is to investigate the degree to which the weight categorisation of a cohort of UK 9-11 year old children differs when estimated through comparison of their BMI against chronological age- and sex-matched UK BMI reference charts (standard UK practice), versus when estimated using reference charts matched to their biological (i.e., maturity adjusted) age. This analysis is undertaken with a view to providing a means of adjusting for expected maturity-related increases in body fat mass among children and adolescents to provide more accurate estimates of obesity prevalence. The process of generating more tailored estimates of weight status may also help to engage parents in discussions about a healthy weight for their child and has the potential to increase acceptance that a child is overweight.

METHODS

Participants

Participants were 407 9-11 year old children who formed the UK sample of the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE).[19] Participants were recruited from 26 primary schools in south west England. Schools were stratified according to pupils socio-economic status (SES; based on levels of entitlement to free school meals; high, mid, low) of the catchment area and weighted by size (large, small), and then approached sequentially to maximise the diversity of the sample of participating children. All Year 6 children in participating schools were eligible to take part. The analytical sample used in this study showed little ethnic diversity, 98% were white British, compared with 90-97% in the local authorities were data were collected, and 87% nationally.

Procedure

Detailed information of the standardised data collection protocol is published elsewhere.[19] Written consent for the study was obtained from head teachers and parents, and assent provided by children prior to participation. A battery of anthropometric measurements were taken by staff trained in the ISCOLE protocol. Standing height was measured to the nearest 0.1 cm without shoes with the participant's head in the Frankfort Plane and at the end of a deep inhalation using a Seca 213 portable stadiometer (Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using a portable Tanita SC- 240 Body Composition Analyzer (Arlington Heights, IL). For both height and weight, two measurements were taken and the mean of the two scores used in subsequent analysis. If the two values differed by more than 0.5 cm for height, or 0.5 kg for weight, a third measure was taken, and the average of the closets two retained in the analysis. Subsequently, Body Mass Index (BMI; body mass (kg)/height (m^2)) was calculated. Overarching ethical approval for the ISCOLE protocol was provided by the Pennington Biomedical Research Center Institutional Review Board, and local ethical approval was also obtained for the UK site by the institutional research ethics committee. Data were entered into a secure central web-based management system, audited by the ISCOLE coordinating centre.

Classification of maturity and weight status. Maturity status was calculated by a non-invasive means (i.e., the Khamis-Roche method),[20] based on the percentage of predicted adult stature that a child had attained at measurement. This method holds that among youth of the same age, individuals who are closer to their mature (i.e., adult) stature are more advanced in biological maturity. A boy of 12 years who has attained 90% of predicted adult height, for example, would be considered more mature than a boy, of the same age and height, who had obtained 80% predicted adult height. The Khamis-Roche method predicts adult height from the child's age, height, and weight, and mid-height of the biological parents. Self-reported parent heights were adjusted for over-estimation using equations generated from over 1000 measured and self-estimated heights from adults.[21] The Khamis-Roche method has been validated against skeletal age in American youth[22] and has also been applied in studies of British youth.[23-25] The median error bounds (i.e. the confidence interval within which 50% of the cases for true height will fall) between actual and predicted adult stature between the ages of 9 to 12 fall between 2.0 and 2.5 cm in boys, and 1.9 and 2.1 cm in girls, respectively.[20]

Maturity status was calculated using z-scores for the percentage of mature height achieved: for group comparisons, z-scores between -1.0 and + 1.0 were considered 'on time', z-scores below -1.0 'late maturers', and z-scores above 1.0, 'early maturers'.[26] To obtain an estimate of biological age, percentage of adult stature was compared with age and sex specific reference standards generated from the UK 1990 growth reference data.[27] Reference standards for percentage of adult stature attained were calculated at intervals of 0.1 years for each sex. Percentages were based upon mean values for stature attained at each age interval, and the mean values for stature attained at and above 18 years of age

(177.6 cm in males; 163.7 cm in females). For example, a girl of 10.5 years who had attained 91.5% of predicted adult stature would have presented a value equivalent to the mean percentage of adult stature attained by UK girls aged 12.0 years. Accordingly, she would be assigned a maturational (biological) age of 12.0 years. For both standard and adjusted calculations of weight status, and in line with the threshold used for population assessment using NCMP data by Public Health England in 2016,[28] overweight and obesity was judged through reference to the UK1990 BMI reference data.[29] Children with a BMI ≥ the 85th centile and <95th centile were classified as overweight, and children over the 95th centile as obese. The difference between the two classification systems (i.e., standard, and maturity adjusted) stemmed from the reference curve against which the child's BMI was compared. To calculate standard classifications, children were matched to the reference curve appropriate to their sex and chronological age in months.

Analysis

We examined whether the classification of weight differed significantly when using standard versus adjusted BMI centiles using chi-square tests, and explored whether there were differences in the number of children reclassified according to sex or maturity status using ANOVA. Effect sizes were also computed to provide an indication of the meaningfulness of statistical differences; η^2 indicates the effect size of F statistics in ANOVA; values ≥ 0.022 are considered a small but meaningful effect, ≥ 0.059 a moderate effect and 0.14 and upwards a large effect.[30] Cohen's d for 2-way comparisons (≥ 0.2 and ≤0.5 considered a small effect, ≥0.5 and ≤0.8 a moderate effect, and ≥0.8 a large effect). Odds ratios of the probability of change in classification were calculated for early, on-time, and late maturers.

RESULTS

The sample comprised 407 children (78% of the 525 involved in the study; 223 girls (55%), Mean age 10.9 years, SD=0.5, range 9.3 -11.8) whose height and weight were objectively measured and whose biological parents self-reported their own heights. Average BMI was 18.3 (SD=3.0), and according to usual age and sex matched cut-offs, 51 (12.5%) children were classified as overweight, and a further 51 (12.5%) obese. Slightly more girls than boys were overweight or obese (26% versus 24%, respectively). No children were underweight (BMI < 2nd centile). On average, girls had reached a more advanced stage of maturity than boys (girls averaged 88% expected adult height, vs 81% for boys). Five percent of boys and 9% of girls were late maturers, 71% of boys and 61% of girls on-time, and 24% of boys and 30% of girls were early maturers.

The results of a 2-way (gender and weight status) ANOVA indicated that there was a significant difference in biological maturity across weight categories ($F(2,401)=38$, $p<0.001$; $\eta^2=0.16$), gender ($F(1,401)=422$, $p<0.001$; $\eta^2=0.51$), and a significant interaction term ($F(2,401)=5.5$, $p=0.005$; $\eta^2=0.03$). The data show a trend for girls to be more biologically mature than boys at this age, for biological maturity to be more advanced in higher weight categories, and for the difference in biological maturity between weight categories to be more pronounced in girls (Figure 1).

Figure 1: Trends in maturation status across weight categorisation

<Figure 1 here>

Comparisons with adjusted values

For the sample as a whole, the mean difference between chronological age and biological age (i.e., age for the given percentage of expected adult height achieved) was 0.18 years (SD = 0.6), ranging from a delay of 1.67 years, to being advanced by 5.5 years. This latter value refers to a girl with a height of 166cm, who had reached 99.9% of her predicted adult height; her weight status did not change when adjusting for developmental stage (she was classified as obese using both systems).

When BMI centile was adjusted for maturation, there was a small decrease in the proportion of children classified as overweight (from 12.5 to 10.6%), and obese (from 12.5% to 11.8%). This related to a small but significant decrease in the mean estimated BMI centile within the sample; standard vs adjusted calculation Mean BMI = 58.2 (SD=30.1) vs 57.4

(SD=28.8) (t(406)=3.09, p=.002; d=0.02). Overall, 5 (11%) overweight or obese boys, and 13 (22%) of overweight or obese girls were reclassified into a lower weight category (Chi square = 583, p<0.001, Table 1). Only one boy and three girls were reclassified into a higher weight category.

Of the 111 children judged to be early maturers, 59% were classified as a healthy weight using standard chronological age growth reference charts (19% overweight, and 23% obese), compared with 67% following adjustment for maturity (13% overweight and 21% obese). Overweight early maturers (i.e., those we consider most important to 'get right' on the basis of requiring intervention or not) were 4.9 times more likely to be reclassified as a normal weight following maturity adjustment than their overweight on-time peers (43% vs 13%; odds ratio = 4.9; 95% CI 1.25 to 19). There was no apparent difference for obese children reclassified as overweight (8% vs 12%; odds ratio = 0.67, 95% CI: 0.10 to 4.4).

Table 1: Comparison of weight classifications following BMI centile adjustment

	Adjusted centiles			
Standard centiles	Healthy weight n(%)	Overweight n(%)	Obese n(%)	Total N
Boys	Chi-square (df=4) = 299, p<0.001			
Healthy weight	139 (>99)	1 (<1)	0	142
Overweight	3 (15)	17 (85)	0	20
Obese	0	2(8)	22 (92)	24
Girls	Chi-square (df=4) = 290, p<0.001			
Healthy weight	164 (>99)	1 (<1)	0	165
Overweight	10 (32)	19 (61)	2 (7)	31
Obese	0	3 (11)	24 (89)	27

DISCUSSION

A comparison of the weight status categorisation of a sample of 9-11 year old UK children according to standard chronological age versus biological age growth charts resulted in the downward-classification of 18% of overweight and obese children, representing 22% of overweight girls and 11% of overweight boys. Only four children (1%) were reclassified into a higher weight category. This effect was more pronounced in girls, for whom almost one in three girls who were reported to be overweight would not have been classified as such using a maturity-adjusted approach. Given the limited age range of the sample, and that boys mature on average two years later than girls, the effect may reach a similar extent for boys but at a later age.

Within this study, we attempted to quantify the difference that adjusting judgements of weight status by a child's level of maturity could have on both population estimates of childhood overweight and obesity, and on the treatment of individual children and families. The strengths of work reside with basing the analysis on a broad cohort of children using robust objective measurement protocols at an age when the effects of puberty are first starting to emerge, and importantly at the age when weight measurement by health professionals takes place and the lack of consideration for maturity is known to be a source of tension between parents and health services. A limitation of this study is that the original UK 1990 dataset bases the norms on which the BMI centiles that we (and health services) use include children of all maturity levels, not only on-time maturers. However, it is likely that the differences observed in our analyses would have been greater, rather than smaller, if the reference data had also standardised for maturity status (i.e., if off-time maturers could be removed). We also note that children from ethnic minorities were under-represented in our sample.

BMI is acknowledged to be a useful but imperfect proxy indicator of fat mass (and excess fat mass) and subsequent health risk.[31-33] Past work has explored how moderating factors such as sex, race and ethnicity may influence the accuracy of BMI in predicting health risk,[34,35] however whereas the impact of puberty on BMI at a given chronological age is well established, few studies have attempted to quantify the impact of biological maturity has on the accuracy of weight classifications.[36] A sensitivity and specificity analysis of BMI in classifying obesity (as measured by body fat mass established through DXA scans, establishing puberty through tanner scales) in adolescents of all ages in New Zealand reported 6-12% of misclassification [36]. Nonetheless, the present study is the first to demonstrate how weight classification may account for children's maturity status in addition to age and sex when benchmarking BMI against growth reference charts, and to report on the likely effects (in terms of changes to weight classifications) of doing so. As the healthy range for BMI increases with age up to adulthood as a reflection of expected healthy increases in body fat during puberty, it is likely that early maturing children and adolescents can be a normal or healthy weight at a higher BMI than their later maturing peers: however, research specifically mapping maturity-adjusted weight categorisation to health risk is needed to formally test this hypothesis.

These findings post two key implications for practice. First, they raise the question of whether we should adjust for maturity when judging whether children or adolescents are overweight. Given the lack of evidence that weight monitoring (as undertaken through the NCMP and similar programmes) results in positive effects on children's health and health behaviours,[7,37] and some evidence that such monitoring activities could undermine their wellbeing and self-concept,[8,9] there seems little risk that adjusting for biological maturity will result in harm (i.e., children are not identified, and do not receive effective help). Whereas the practice could be of benefit if we are better able to raise awareness and engage with parents whose children remain classified as overweight or obese following adjustment as a result of showing that we have tailored the judgement to their child's level of biological maturity. Second, the findings suggest that early maturing children are particularly at risk of misclassification; this group are already known to be at greater risk of poor mental health[38-40] and may be particularly susceptible to the negative impact of such evaluations as they generally hold more negative perceptions of the physical self (lower perceptions of attractiveness, sports competence, and fitness.[41] As such, early maturing children and adolescents represent a vulnerable group with whom we should be particularly careful to minimise the potential unintended negative consequences of health policies.

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Competing interests:

None to declare

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Details of contributors

Fiona Gillison led in the drafting of the paper, development of the idea for the use of the ISCOLE data in this way (with SC), conduct of analyses (with CB). She was a CI for the UK ISCOLE site, involved with data collection, researcher training and quality oversight.

Sean Cumming provided expertise in the assessment of maturity and interpretation of findings, contributed to the development of the concept for using the ISCOLE data in this way (with FG), and contributed to the drafting of the paper. He was involved with data collection and coordination for the UK ISCOLE site.

Martyn Standage is the PI of the UK ISCOLE study site, and contributed to the drafting of the paper.

Catherine Barnaby provided input and expertise to the analysis of the study data and contributed to the drafting of the paper.

Peter Katzmarzyk is the PI of ISCOLE across the 12-country sites, responsible for the design of the original study and oversight of data collection and analysis, and contributed to drafting the paper.

We confirm that all authors had access to all of the data and can take responsibility for the integrity of the data and accuracy of the data analysis.

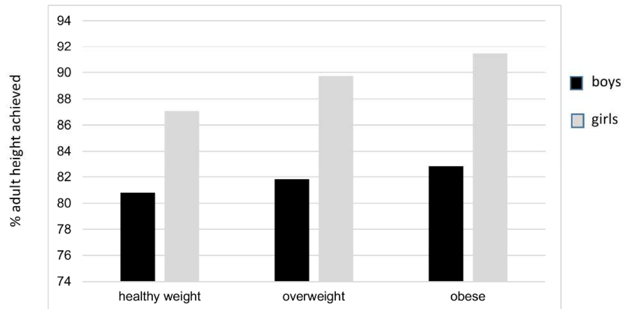
Data sharing statement

Data sharing: no additional data available.

URL to study protocol:

http://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-13-900

Figure 1: Trends in maturation status across weight categorisation



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