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Abstract

Gender bias against girls in nineteenth-century England has received much interest but establishing its existence has proved difficult. We utilise data on heights of 16,402 children working in northern textile factories in 1837 to examine whether gender bias was evident. Current interpretations argue against any difference. Here our comparisons with modern height standards reveal greater deprivation for girls than for boys. But this result cannot be taken at face value. We query whether modern standards require adjustment to account for the later timing of puberty in historical populations and develop an alternative. Gender discrimination remains, although its absence amongst younger children precludes an indictment of culturally-founded gender bias. The height data must remain mute on the source of this discrimination but we utilise additional information to examine some hypotheses: occupational sorting, differential susceptibility to disease, poorer nutrition for girls, disproportionate stunting from the effects of nutritional deprivation, and type and amount of work undertaken, specifically labour additional to paid work in the domestic sphere. Of these, we favour housework as the main culprit, factory girls undertook more physical labour than factory boys and this was reflected in disproportionate stunting. The 'double burden' was, and remains, a form of gender discrimination.

Introduction

The existence of gender bias has been of interest to development economists and historians alike. While unequal treatment of girls is evident in a number of countries today, there is less certainty about whether it existed in the industrialising countries of the past. Evidence for nineteenth-century British households has been mixed. Changed employment opportunities for women and girls over the course of industrialisation has led to expectations of poorer treatment within the household because the ability of females to contribute to household resources was reduced. Some evidence points in this direction: declining opportunities to provide resources through agricultural labour, gleaning and common rights was reflected in declining heights of rural women, probably occasioned by worsening nutrition (Humphries 1990; Horrell and Humphries 1992; Nicholas and Oxley 1993); older women suffered higher rates of mortality in these areas (McNay, Klasen and Humphries 2005); and high rates of female mortality have been ascribed to the large incidence of tuberculosis brought about by malnourishment in low female employment areas of Cornwall (Ryan Johanssen 1977). Differences in literacy too seem to suggest gender bias against females in education, affecting their human capital acquisition and undermining their capabilities. Nationwide while over 60 per cent of men were able to sign their names in the Parish register on marriage in the nineteenth century, this was true for only 43 per cent of women (Schofield 1973 p.453). But the links with women's economic activity and ability to generate resources for the household are opaque, and may even be inverted; female illiteracy was particularly high in the industrial areas, where more women worked for wages (Sanderson 1972, Laquer 1974).

Others have been sceptical about some of these relationships. There is little evidence for female disadvantage among medieval and early modern children and the lack of differential mortality observable between girls and boys more recently refutes the idea of systematic gender bias (Harris 1998, pp.413-21, 2008, pp.159-69). Closer examination of the possible existence of gender bias in nineteenth-century England is required but care needs to be taken over the metric and sample used for its identification.

Although lack of legal and political rights and female subjugation in many nations today, alongside the 1 million women found missing in India (Sen 1990), offer incontrovertible proof of the existence of gender bias, more subtle forms of inequality have proved harder to detect. Methods designed to formally identify gender bias in the treatment of children through expenditure (Deaton 1989) have often proved inconclusive in practice (see for example Subramanian and Deaton 1991). Neither can direct observation of differential expenditures on females and males be used to infer the existence of gender bias. Better economic opportunities for males imply they are likely to devote more time to paid work which then requires the male to receive a larger share of the goods within the household to compensate for the lack of leisure in order to equate levels of utility or welfare (Horrell and Oxley 2013). Formally:

in a simple unitary model of the two person household (a male and female, $_m$ and $_f$), utility is defined across goods, x, and leisure, L

$$U = U(x_m, x_f, L_m, L_f)$$

and maximised subject to time and budget constraints

$$p(x_m + x_f) = w_m H_m + w_f H_f$$

where p = price, w = wage and H = hours of work

Outcomes here are essentially driven by the budget constraint. Equal wages ($w_m = w_f$) will generate an equal consumption of goods and leisure for both people, but it is unlikely that we would observe equal consumption for each person if wages were unequal. Specifically, the higher wage to one individual will raise the price of that individual's leisure and so, *ceteris paribus,* that person will consume less leisure. In the egalitarian household equality of utility for each individual will require a compensating higher consumption of goods by the high earner: an apparent bias towards earners in the distribution of material welfare. Observed differences in consumption outcomes cannot then be taken as unequivocal evidence of gender bias, we also have to account for other aspects of welfare. Another implication of the model is that 'leisure' – which includes unremunerated work in the household sector – is unlikely to be compensated.

These considerations present problems for examining gender bias in the treatment of children in early nineteenth-century England. What metric can be used to capture the relevant aspects of welfare and how can differences in earning potential be controlled for? One possibility is to consider a situation where economic opportunities were very similar for both sons and daughters, so negating the impact of earning power on intra-household distributions. Rarely did girls and boys have the same opportunities but work in the textile factories of North West England constitutes an exception. Here we can see whether boys were irrationally (uneconomically) favoured over girls. But by what metric should we ascertain this? Mortality data has the disadvantage that it is only available by geographical area, not by occupation as we require. Furthermore, the multitude of factors affecting mortality, for instance biological differences in susceptibility to disease, make it difficult to unambiguously discern gender discrimination where sex differences are relatively small (Harris 1998, 2008). Consumption data are too infrequently recorded for the early nineteenth century to allow meaningful analysis and, in any case, rarely allow us to distinguish between girls and boys in the household.

Heights can capture the key elements we require. Family decision making can be bought into focus by employing anthropometric measures of wellbeing because net nutritional status is sensitive to distributional inequalities. Specifically, height tells us about cumulative net nutritional status from conception to maturity, even capturing conditions at pre-conception plus maternal health and wellbeing. It reflects nutritional intake and demands on that intake from fighting off disease and physical work effort at young ages. It captures food consumption, admittedly only one aspect of the consumption we would ideally like to observe but probably the most important as other types of consumption would be more limited and less likely to be differentiated by gender among these less-well-off families at this time, for instance spending on rent, fuel and maybe even clothing. Height also captures leisure including non-market activity, as the corollary of work, another aspect of welfare in which we are interested. Disease environment will also impact on height but this is unlikely to be differentiated by gender for these locationally-identical children. Height is particularly responsive to resources at young ages (conception-2 years) and is closely related to life chances as measured by mortality and morbidity. For the factory children we consider physical maturity likely occurred around age 19 to 20 for English girls and 21 to 22 for English boys, later than today.[1] Prolonged catch-up growth can lead terminal height to understate disparities experienced in childhood. A more sensitive measure is height for age by gender. Specifically we compare factory children's heights with modern standards to see whether girls and boys show equal degrees of stunting as a result of the deprivation experienced in this era.

Our data comprise the heights of 16,402 children, with equal numbers of boys and girls, collected by Leonard Horner, Inspector of Factories, in 1837 and reproduced in BPP 1837 (99), *Factory Children*, pp. 6-11. We are indebted to Peter Kirby who has computerised and made available this data set.[2] After describing the earning opportunities of factory children in Lancashire and demonstrating the similarity in availability of work, we consider the heights data. Comparison with modern height standards raises issues about the appropriate yardstick and the impact of gendered height trajectories, so suitable comparators are developed. Our results indicate considerable discrimination against female children. We speculate on the source of this bias. Differential access to food is one possibility, different susceptibility to disease environment another, and systematic differences in physical workload a third. We consider each of these possibilities and conclude that of all the candidates through which female disadvantage may operate, greater work effort than the physical frame allowed is the most likely. Girls may have been overworked, both relative to their male siblings and in relation to their own physical capabilities.

The earnings of children in textile factories

Crucial to our analysis of children's heights is establishing the similarity of earning experience for factory girls and boys. In 1835 56,000 children under age 13 (the definition of children under the Factory Act of 1833) worked in textile factories in the UK, constituting about 16 percent of the total textile workforce (Nardinelli 1990 p.4, 68). This employment was concentrated in Lancashire, Yorkshire and Cheshire. Children with fathers in textile factory work were very likely to be working themselves. Fifty five per cent participated in the labour market compared with one quarter of children in families overall in 1817-39 (Horrell

[1] See Horrell et al (2009).
[2] Peter Kirby, The Physical Stature of Children in Northern English Textile Districts 1837. UK Data Archive 2010 SN6426

and Humphries 1995 pp.492-3) and their contribution to household income could be substantial. Although children in low-wage agricultural households only contributed around 4.6 per cent of total income, they contributed some 28.2 per cent of household income in factory families (ibid p.491). Children with factory fathers might start work at age 8, those whose fathers worked in outwork or agriculture delayed their entry into the labour force until ages 10 or 11 (Horrell and Humphries, 1997 p.53). Plentiful work and good earnings meant children were economic assets to these industrial families. But were girls and boys equally valuable?

As measured by earning power, they were. Factory work in nineteenth-century Lancashire, particularly in cotton but also in the surrounding wool and flax industries, offered very similar pay and employment opportunities to girls and boys up to the age of 16. The collection of data on earnings, heights and weights of around 1,500 children attending Sunday schools, two in the Manchester area and one in Stockport, by Mr Cowell and Samuel Stanway for the Parliamentary Report of 1833 (1833 (450) Factories Inquiry Commission, D.1, pp.87-89), show the close correspondence between male and female earnings in factories, compared with the poorer experience of girls in non-factory work, and also their high level of earnings relative to non-factory males (table 1).

These observations are supported by the detailed work on earnings by occupation in various industries around the country for girls and boys conducted by Paul Minoletti (2011, app. B; 2013) in his analysis of the information contained in the Factory Inquiry Commission (BPP 1834, XIX, pp.427-435). A summary of the information (table 2) reveals both the high level of wages and the equality of wages between girls and boys until their mid-teenage years in the textile industries around Lancashire. This was true for Lancashire cotton, West Riding woollens and Derbyshire lace. Here wages remained relatively high into adulthood and the industries offered plentiful employment to females. Minoletti's analysis also details the jobs done by girls and boys in eight cotton factories. Both were piecers and scavengers for mule spinners and both were weaving on powerlooms. Although it was mainly girls who spun on throstle spinners, some boys were also engaged in this task. Boys and girls were starting work around the same age, were engaged in similar tasks and received equivalent remuneration. They were therefore equally valuable to their families in these factory districts so differences in treatment at young ages cannot be attributed to any economic rationale, instead they could be indicative of culturally deep-seated gender bias.

The height data

The main regulation of employment in factories in this period came from the Factory Act 1833. Although previous legislation had been enacted, it related only to cotton mills and, initially, apprentices. The Health and Morals of Apprentices Act 1802 limited the working hours of apprentices aged under 21 in cotton mills to 12 hours per day. The Cotton Mills and Factories Act 1819 extended this to all child employees aged 9 to 16 and precluded the employment of any child under 9 years of age in cotton mills. Notably parents were responsible for verifying the child's age. Subsequent amendments were made to this Act in 1825, 1829, and 1831 with the main provision of the last being the outlawing of nightwork for people under 21. But the main extension of regulation came with the Factories Regulation Act 1833, 3 and 4 Will. IV. c.103 (Labour of Children, etc., in Factories Act 1833 (Althorp's Act)). This extended coverage of textile factories from cotton to also encompass wool and flax (silk remained exempt), outlawed the employment of children under 9 in the textile factories; ensured children aged 9 to 12 worked no more than nine hours per day and no more than 48 hours per week and additionally insisted on two hours of education per day for this age group; children aged 13 to 18 were not to work more than 12 hours per day; no child under 18 was to work at night (8.30pm – 5.30am); and for those working a 12 hour day an additional 1 ½ hours were to be allocated for meals. The Act came in to effect 1st January 1834, but phased in the 9-hour day restriction for the under 13s: there would be six months grace on the employment of 10 year olds, 18 months for those aged 11, and 30 months before the Act applied to 12 year olds. Thus it was not fully operational until March 1836. Among the children in Horner's study, only those aged under 12 are likely to have had any benefit from this legislation

As these regulations were age based, the determination of the age of working children became critical. Prior to the certification of births from 1837 the nearest proof of age was from baptism but there was no requirement to baptise and it was not practiced on young children by many non-conformist religions, therefore parental honesty often had to be relied upon. Parents had an incentive to pass their children off as older than they were either to gain employment before age 9 or to be allowed to do a full 12 hour day before age 13. The 1833 legislation changed the onus for verification from the parent to the employer who was required to use a surgeon to certify the child's age. These surgeons were local, often the General Practitioner and, it is thought, willing to collude in certifying older ages (Kirby, 2013, pp.105-6). To monitor their honesty, the legislation also provided for routine inspection of factories and appointed four inspectors, to cover (rather ambitiously) some 4000 mills. This was only changed with the Factories Act 1844 which allowed the inspectors to appoint certifying surgeons.

Leonard Horner, appointed Inspector of Factories, was concerned about the amount of deception practised in the certification of children's ages: 'It was evident that there had been either the most culpable negligence on the part of the surgeons, or that fraud had been very extensively practised upon them' (Horner, 1837 BPP (99), p.1). Horner sought an alternative. In his supplementary instructions to Surgeons to grant Certificates of Age, Horner advised that the first step to determining age was height, thence breadth of chest, muscular strength and health. He stressed that the legislative focus was on physical ability not age.

But he saw the need to develop a clearer standard. It is against this backdrop that Leonard Horner collected the heights data in 1837. He wanted to enable Factory Medical Inspectors to accurately judge the age of children thus preventing the employment of those deemed too young. To this end he requested the surgeons to volunteer some of their leisure time to make returns of children's heights by age, specifying they should "confine the observation to the children of the working classes; to measure only those whose real ages can be ascertained with tolerable certainty; to distinguish the males and females; to exclude those who are not in an ordinary state of health, and to distinguish the measurements by differences of half-years" (Horner, BPP 1837 (99) p.2). The data are also classified by the location of the surgeon: large town, small town and rural district. It is thought that the measurements were taken at the time of applying for a factory job, which could be at any age, not just at the discrete jump in hours, but there may also have been the measurement of those already in situ. Horner's advertisement issued in 1836 stated that "no child between 9 and 13 years of age … allowed to remain, in such factory, without the certificate" which reiterated the ruling made in the 1833 Act.[3] Pre working-age children were also measured. The large towns covered were Leeds, Manchester, Bolton, Halifax, Preston and Stockport.

Despite Horner's strictures there remains some scepticism about the accuracy of the data. There are doubts about who exactly were the children whose heights were collected. Kirby (2013 p.111) considers them all to be applicants for factory work, presumably because they were furnished by the seventy-two surgeons who were certifying children's ages and hence eligibility for work in the factories. A careful reading of the report suggests this to largely be the case. Horner notes (1837 (99) p.5) 'The measurements were confined, I believe, to the children of the working classes, but not exclusively to those employed in factories' (hence the under 9s). Thus some children may have other occupations, but it is impossible to discern which ones. The factories were in different locations but note the very similar distribution of the sample by location and gender.[4] 'Many factories being situated in the vicinity of the smaller towns, the persons employed in them partake, in some degree, of the character of a rural population' (ibid p.5) again endorses the idea that these were children measured for factory work. More important is whether Horner's instruction to only take children whose age could be ascertained with certainty was followed.

How accurate are the height for age measures? Unfortunately here Horner exhibits some scepticism. As part of his instructions to the surgeons and the reasoning behind his desire to get standard heights as a way of determining age he sends some tables previously collected by Mr Harrison and Mr Baker in 1833 and known to be of factory children. Horner is pleased that 'the averages obtained [from the 72 surgeons in 1837] ... correspond very nearly with those of Mr. Harrison and Mr. Baker' (1837 (99) p.4), but because of the 'extraordinary variety in height of children, nominally of the same age, which these returns exhibit, there is much reason to fear that in the greater number of instances, the real ages have not been ascertained with certainty, but have been set down from the statements of the children themselves, or from those of their parents; and upon neither can much reliance be placed.' (ibid pp.4-5). This is worrying. Indeed, when Horner corresponds with Harrison saying he wants more information on height for age, Harrison replies saying that the

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[3] London Gazette 24[th] June 1836, reproduced in 1837 BPP [73] Reports of Inspectors of Factories, p.20.

[4] The distribution of the Horner sample is: 8041 girls (49% of total sample), 20.6% large, 38% small, 41.4% rural; and for 8361 boys 19.8% large, 36.6% small and 43.5% rural.

difficulty of getting at the real ages of children under age 13 (the age at which children are legally allowed to work 12 hours in factories) will be great. ‘With respect to such children the truth is very rarely told, and most every conceivable expedient is adopted to produce an erroneous impression on the minds of the surgeons’ (ibid, p.3).

To help ascertain the reliability of Horner’s data we can turn again to Stanway’s study of Sunday schools in Manchester and Stockport in 1833 (table 3). Taking only those Sunday school attendees who were classified as engaged in factory work and comparing their heights with those of Horner’s children in large towns in 1837 shows Sunday school children were slightly taller at each age. At age 9 years, the difference is small and insignificant: 0.15 of an inch between boys, one-quarter of an inch between girls. The gap then widens, especially for girls who, by age 14, are just over 2 inches shorter. The disparity between boys is a little less, 1½ inches. This gap might be expected as, by their attendance at Sunday School, these children may have come from the better-off end of the group of factory operatives. Certainly the occupations listed for the seventeen year old non-factory boys indicates this slightly better-off bias: bleacher, painter, joiner, grocer, farmer’s servant, machine maker, wire drawer, tailor, brush maker, flour dealer, handloom weaver, brazier, hatter and silk weaver. It seems at least that those children measured in large towns in 1837 were very likely factory operatives.

Harrison too had thought about similar problems with his earlier sample. He must have collected his data (1409 children measured, between the ages of 11 and 18) around 1834 because he makes the following observation about the previous age at which 12 hours could be worked being 11.[5] To quote from Harrison’s letter to Horner:

> The investigations were made on the first coming into force of the Factories Regulation Act, and as the children and their parents, with few exceptions, did not know for what object the inquiries were made, nor how they would affect their interest, they had no inducement to give in false statements of age. The greatest doubt must exist with regard to the average of the children represented to be between the ages of 11 and 12 years, as 11 was at the time of the examination the lowest period at which children were allowed to work 12 hours a day, and the parents of such children as were under that age had a strong inducement to make false statements; but as the parties did not then know much of the provisions of the Act, it may perhaps be regarded as an approximation to the truth. Above 11 there was no conceivable motive for practising deception. (BPP 1837 (99) p.4)

It was not until March 1835 that 11 year olds were restricted to a 48 hour week, with a maximum 9 hour day. So two things emerge that give us more confidence in this height for age data. First, Harrison reckons his data is not subject to biases in age reporting. Horner’s averages, particularly for boys, are much the same as Harrison’s, suggesting no large scale bias in the height for age data. Second, and more important, we have a natural experiment. When Harrison collected his data the legal age for working twelve hours was 11, so the most

[5] His correspondence with Horner is 16 August 1836, but it relates to “Mr Harrison[‘s] … letter to the late Mr. Rickards, which forms a part of the Report of the latter to the Secretary of State, printed by the House of Commons, in August 1834.”

doubt was expressed about those stated as aged 11, as some of these may have been only age 10. If so, heights at age 11 are likely to be low for the reported (rather than actual) age. When Horner collected the data, the legal age was 13 and we might expect low heights for age around ages 12 and, particularly, 13, as parents elevated their children's ages. Harrison thought he had accurate ages for 12 or 13 year olds as these were both allowed to do 12 hours (under the 1831 Act, the 1833 Act for these age groups had not yet come into force). That Horner's average heights for these age groups are, in his view, much the same between the two samples suggests age reporting was more accurate than he allowed (table 4).

The comparison suggests that the only disparity is with girls, with those in Horner's sample on a par with those collected by Robert Baker in Leeds (table 4), but somewhat reduced compared with Stanway (Sunday Schools) and Harrison (Preston). However, it is difficult to say anything definitive because Horner's data includes children living in some of the worst large towns, such as Manchester , whose poor environment would have been worse than that in Preston and Stockport and so have adversely affected heights. Leeds was also a large town, hence the comparability with Horner's sample.[6] Furthermore, although Horner's 12-13 year olds were a little shorter than those in the other samples, which may indicate 12 year olds being categorised as age 13 to enable them to do 12 hours work per day, a similar understatement occurs at ages 13 to 14 when no such deception would be necessary. Note from table 3 earlier that Horner's children from large towns are also shorter than Stanway's Sunday school factory operatives, but these Sunday school factory operatives themselves are very similar in height to non-factory children (table 5), suggesting few problems with height for age amongst the school sample. Here again there is no large scale jump in the discrepancy between the samples around the ages at which there would be the greatest incentive to lie (table 3). Overall, these comparisons suggest there is no large systematic bias in the heights collected by Horner.

Of course, this only establishes whether average heights look like those of the appropriate age group, not whether taller children were being passed off as older ones. But we can hypothesise what the distribution would look like if this were the case.

If there was an incentive to lie about age for children tall enough to look age 9 (entry into work) and 13 (full, 12 hour day) what would we expect the distribution to look like? We might imagine these children would fit neatly into the actual distribution for ages 9 and 13 leaving the dispersion for this age category largely unaffected. But we could also plausibly assume that it was the tallest in the true age group (8 and 12) that upwardly adjusted their ages thus taking observations from the right hand tail of the height distribution and leaving a skew in the data at these ages. Specifically it would be a negative skew (mean < median< mode) for ages 8 and 12. There is some evidence for this among 8 year olds, particularly for girls, but the degree of skewness is small and less than that found for age 9, whereas there is no evidence of negative skew at age 12 (table 6).

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[6] The populations of these towns in 1831 were 182,000 in Manchester and 123,000 in Leeds, compared with only 34,000 in Preston and 36,000 in Stockport. Mitchell (1988) pp.26-7.

As a rider to this, Horner himself thought the problem was less about lying about age and more taking the form of older children presenting to get the certificate and then handing over or selling the certificate for a younger child to use. This behaviour was certainly unethical but, if this was what the surgeons were recording, it would not introduce any bias into our data on height for age. Finally, the shape of the height-for-age distribution in Horner's sample is replicated for factory children in 1876, by which time certification of births provided reliable age data (Roberts 1876 p.682).

Gender discrimination as indicated by the height data

Horner's data on heights (table 7) shows girls to be taller than boys from the age of about 10.5 to age 14.0, reaching a maximum difference around age 13. On the face of it, the greater height of girls would appear to argue against gender bias in Horner's factory sample. A similar difference came as a surprise to Harrison when he examined his Preston data and he wrote to Horner:

> The most remarkable feature of the present table is, that the average height of the females examined, with two exceptions, exceeds that of the males. This is a result for which I was not prepared, and …. it would seem to indicate that between the ages of 11 and 16 the growth of the female is more rapid than that of the male.[7]

Harrison's surprise at girls growing taller implies widespread experience of excessive female stunting that was only challenged where girls were able to contribute on a par with boys, such as in the cotton manufactories of Preston. It bespeaks how differently contemporaries understood human growth, about how girls and boys diverge.

Today girls *should* be taller than boys at certain ages (around 9 to 13.5 years). This is down to puberty. The differential timing of puberty, and the rapid phase of growth that precedes it – the 'adolescent' or 'pubertal growth spurt' – places girls and boys onto different growth trajectories. Typical individual velocity curves are illustrated in Figure 1, reproduced from the classic study by Tanner, Whitehouse and Takaishi (1966a) which established British standards in the 1960s. In young children there is little sexual dimorphism but around age 9 girls start their adolescent growth spurt, peaking around 12.1 years, just prior to menarche. Growth then diminishes rapidly. Boys start their spurt around three years later, leaving them shorter than girls in the pre-teen years but catching up around age 14 when their growth peaks. Girls then complete their growth two years earlier than boys, so reaching lower terminal heights. There is natural variation between individuals in the timing of these events, and typically, under conditions of poor net nutrition, growth is lower, puberty later, and the road to maturity longer.

In 1897, Karl Pearson, Professor of Applied Mathematics and later Eugenics at University College London, wrote despairingly, 'The difference of the ages of puberty in

[7] Letter 16 August 1836. In BPP (1837 (99) p.3.

boys and girls renders it in fact impossible to make any comparison from about the age of ten to an adult age' (1897, p.296). Today, a widely used solution to this problem has been to develop sex- and age-specific standards for mean height (μ) and standard deviation (σ). What then should the standard be? A useful starting point is an established and accepted benchmark produced by the World Health Organisation in 2007 (henceforth WHO_{2007}). It is "designed specifically for the … purpose, and … been recommended for use as a WHO reference for use in maintaining the nutrition of countries or subpopulations within countries" (Tanner, 1989, p.206). Initially based on the cross-sectional measurement of heights of American children aged 5-19 years (National Centre for Health Statistics 1977), WHO_{2007} has been adjusted to mesh with the WHO Multicentre Growth Reference Study (MGRS) for children 0-5 years of age. This in turn was designed to include children from a variety of countries (Brazil, Ghana, India, Norway and Oman) to achieve a standard deemed suitable for assessing the growth patterns of children worldwide, including those in poorer countries (de Onis et al, 2004, p.s27). Eligibility for inclusion in the study required 'environments supportive of unconstrained growth' and consequently focused on the affluent (WHO 2006a, p.56, 2006b, p.7). WHO_{2007} thus offers a model of human biological potential – of the growth pathways of healthy and well-nourished girls and boys – against which we can measure the performance of other populations, past and present.

The velocities suggested by the factory data are very different to the WHO $_{2007}$ standards, suggesting a substantial delay in growth behind more recent populations (Figure 2). One interpretation is that growth slows massively as children commence factory work (the rate of growth between 8 and 9 years is considerably greater than between 8.5 and 9.5 years). The similarity of girls' and boys' trajectories in the nineteenth-century factory data also stands out, as they should be very different and are not. Girls' velocity was slowing at the very time that WHO girls accelerated. Likewise as WHO girls peaked and declined, Horner's factory girls were only just moving into the growth spurt. This suggests profoundly delayed growth for girls, more so than for the boys.

Do other historical data replicate this pattern or is the factory data anomalous? We compare with other series reported in Tanner (1981, pp. 156-9) (Figure 3). Swedish data collected between 1883 and 1968 show the secular increase in height (Ljung et.al. (1974), p.247). Superimposed on this graph are the factory data 1837 and data from the Royal Orphanage of Berlin collected around 1730 by C. F. Jampert (Tanner 1981, pp.88-9). Although the Berlin data are based on individual observations, Jampert was concerned to get children who were "grown in healthy proportion" and representative of their age. Our data fit smoothly within the secular trend. All the eighteenth and nineteenth-century data also exhibit some of the trends that appear anomalous when compared with today's data. Specifically later and more pronounced growth spurts for girls and a greater similarity in the trajectories of girls and boys. American slaves too suffered delayed growth and, importantly for our purposes, showed much the same dip and double-dip in height velocity as the factory data, particularly for girls (Tanner 1981 pp.160-67, from Steckel 1979). In general, our data seem to be historically representative in both their positioning in the secular trend and their depiction of the velocity of growth.

The difference between a study group and the WHO_{2007} standard can be measured in metres, centimetres or inches. A more powerful and intuitive gauge of distance is the z-score, which is based on the normal distribution and is measured in standard deviations from the centre. The z-score measures the relative distance of an individual value away from (above or below) a specified standard μ with standard deviation σ, both of which are specific to each age-sex combination[8]:

$$z = \frac{X_i - \mu}{\sigma}$$

This yields a height-for-age z-score, or HAZ. One advantage of this method over, say, the use of percentiles is its infinitely finer gradations (many historical populations cluster in the first percentile) (Wang and Chen 2012). Its other great merit is that it is easy to read statistical significance from the z itself. As noted, z-scores are measured in standard deviations, and standard deviations capture the amount of the population that falls within a given range. From the rule of a normal distribution, 68% of the population falls within one standard deviation of its centre (z=±1); 95% falls within plus or minus two standard deviations (z=±2), and 99.7% of the population falls within three standard deviations (z=±3). Thus, a z-score of -1 would imply the individual has a height that falls one standard deviation below the mean placing that person in the 15th percentile of the height distribution. A z-score beyond ±1.96 is deemed statistically significantly different from the mean because of the comparatively low chance ($p<0.05$) of belonging to a normal distribution of this mean and standard deviation. For a sample to have a median value that far removed implies a greater likelihood that the sample is drawn from a different population, with a different median value.

WHO_{2007} gives us our modern standard for healthy, well-nourished growth by age, and we use z-scores to tell us just how far below the modern standard (WHO_{2007} 50th percentile) were the nineteenth-century factory children. Our computations use mean height for given age range in Horner's data (e.g. 8 to 8.5 years) and compare these with the relevant WHO_{2007} mid-point (for this example, 8.25 years). Let us explain how we expect z scores to reflect deprivation and gender bias. Deprivation is indicated by a z score below 0, the further below the greater the deprivation, and z-scores below -1.96 are statistically significantly below the WHO_{2007} standard. Gender bias would be indicated by a gap in these z scores, specifically gender bias against girls would be implied by z scores that fall below those of boys, implying greater deprivation for girls. This is what our data show (table 8 and Figure 4).

Factory children were unequivocally shorter – significantly so – compared with modern children. When measured, not simply against each other, but against what might be considered their biological potential – the modern pattern of growth for well-nourished girls

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[8] Technically, z-scores are calculated with a more complicated formula that includes a term correcting for skewness (the power of the Box-Cox transformation); as this is unity for the WHO_{2007} height data, the equation resolves itself into the simple form we cite above.

and boys today – it appears that factory girls were at an even greater disadvantage than the boys (comparison of HAZ yields t= -8.4, p<0.0005). Factory girls fell further below modern standards than boys at nearly all ages in the study.[9] Girls were below boys from age 8 to age 13 and, as they got older, they were falling further behind modern standards than were boys. This is *prima facie* evidence of gender discrimination.[10]

Appropriate standards for anthropometric comparisons by gender

It is at this point that we wish to complicate matters. Interpreting HAZ is not as straight-forward as generally held. It is claimed that, 'as standardized quantities, they are comparable across ages, sexes, and anthropometric measures' (Wang and Chen, 2012, p.29). It is typically assumed that variations in the timing of puberty are adequately accounted for by the widening distribution of standard deviations with age. We suggest they are not.[11] These only accommodate natural variation within well-nourished modern populations. They cannot capture the shifts in the tempo of growth inflicted by extensive nutritional deprivation often seen in historical populations.

The indication from the Horner analysis so far is that the timing of the growth spurt has changed and the factory children were measured at ages before peak height velocity was achieved. What is known about the historical timing of puberty? Puberty is quite plastic. A recent study of 20th century Danish children found declining ages for the both the onset of pubertal growth and peak height velocity over the space of just four decades (Aksglaede et al 2008). Velocity is clearly related to puberty and, for girls at least, this is reasonably easily ascertained by age at menarche, with this representing the end of growth. Table 9 details the gleanings on age at menarche and there is evidence of a widespread decline over time. Menarchal age appears to drop in parts of Europe from around 16-17 years in the mid-19th century, to 12.5 to 14 years of age one hundred years later, hovering around 12.5 years thereafter (Gohlke and Woelfle 2009, p.381). The USA, Japan, and China, among others, all exhibit similar trends. Age at menarche falls as stature increases, in response to improved net nutrition.[12] For example, in South Korea menarche fell from 16.8 years to 12.7, while girls' stature increased from 149.23 to 161.75cm, for a study of women born between 1920-86 (Hwang et al 2003). It is still falling (Ahn et al 2013). For the period we are looking at age 15-17 seems a fair assessment for working class girls, while those from higher classes reached menarche earlier. We would thus expect peak height velocity to occur around or after

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[9] Note that the percentage differences reveal the same basic pattern (table 8) so the result is not an artefact of using the z-score as a measure.

[10] We might query whether this pattern of z scores could be generated by children being recorded as of older ages. We test this using a realistic reallocation of children's ages and their related heights and find the gendered pattern of girls' z-scores lying below those of boys remains.

[11] A similar note of caution has been sounded regarding body mas, see Silverwood et al (2009). Thanks to Evan Roberts for drawing this to our attention.

[12] For a recent meta-analysis of current medical literature, see Yermachenko and Dvornyk (2014).

age 14, ages that are at the limits of our factory data. Nineteenth-century factory girls had growth trajectories that were somewhere between 1½ and 3 (maybe even 4) years behind today's girls. For boys the pattern is harder to discern, signs of puberty are less immediately obvious and so more difficult to accurately date. From the information available it would appear that puberty for boys may have been delayed by between ½ to 2 years behind today's population. Of course, boys may be less delayed than girls if they were less deprived, therefore a different delay to puberty may itself be indicative of gender bias.

Shifts in the timing of puberty intimate variations in the tempo of human growth. In turn, this complicates the relationships between a deprived or historical population and a modern standard, and should modify our expectations regarding HAZ for girls and boys. Let us begin by considering growth and the nature of individual versus grouped data. Individual velocity curves measure how one individual grows over time. However, the adolescent growth spurt can occur for any individual within quite a wide range of ages (in Tanner's study, peak velocity was reached for girls between 10.5 - 13.5 years of age, and for boys 12 - 16 (Tanner et al 1966a, p.461)). Averaging numerous individual growth curves that are out of phase with each other (the 'phase-difference effect') makes the trajectory of growth look different: the individual is peaky, the aggregated more flat. Tanner et al observed the manner in which the individual peaks in growth velocity are subdued when summed, in their illustration reproduced here as Figure 5. The more dispersed are the underlying data, the flatter the combined curve.

Most height reference standards are not constructed with longitudinal measurements, but with cross-sectional data, and velocity measures the interval between average stature at different ages.[13] This is largely true of WHO_{2007} and applies to Horner's data as well. Here the problem is not summing individual velocity curves, but in aggregating individuals who may be at different phases of development, a problem most prominent around puberty when rates of growth first escalate then plummet. Mixing individuals maturing at different rates dampens group velocity compared with an individual velocity curve, and concomitantly, standard deviation widens. Such a group curve will neither reach the same peaks, nor the same troughs: late developers will depress peak velocity, pulling the average down, while growth will appear elongated by the presence of late developers pushing the average upwards at later ages. Variation in stature and velocity will be most visible in the outer centiles.

This has particular implications for deprived growth. Deprivation typically delays growth, clustering late developers in the lower ranges of the distribution. We can see how, even within the affluent WHO_{2007} data, natural variation means that growth varies between the top and bottom of the distribution. Consider two extremes, those at 0.1 percentile, and at 99.9 percentile. Their growth velocities, as measured by monthly changes in stature, are traced in Figure 6 below. For the top boys, it is clear that performance was maximised by

[13] It should be noted that no individual is likely to follow the path drawn by these cross-sectional changes in height. It would be 'pathological' to remain at the extremes of growth (Tanner et al. 1966b, p.613). Instead, there will be churning in the personnel in a given band, most notably at the outer centiles of growth.

consistently high rates of growth – the single most important factor. For boys at the bottom, the overall rate of growth was much slower and peaked lower but velocity then decelerated more slowly, and growth persisted beyond age 19 (the cut-off for the data), suggesting the presence of late developers. Likewise, tall girls grew faster for longer and reached a higher peak velocity than shorter girls, who grew more slowly and had a steeper approach to their lower peak. This was followed by a gentler decline in velocity and protracted maturity.

We should not expect a deprived population to exhibit a constant negative z-value over the growing years, because nutritional deprivation reduces height *and* changes the tempo of growth, reducing absolute velocities prior to puberty, delaying entry into the adolescent growth spurt, but raising velocities after the peak. We need to model these delayed growth trajectories for boys and girls. To this end, we can deploy a new growth reference standard for a modern but comparatively disadvantaged population, based on Indian school children from the upper socioeconomic strata (those attending fee-paying schools) (Marwaha et al 2011). This Indian standard deploys the same methodology as WHO_{2007}, facilitating comparison.

Consider a deprived female population: Indian schoolgirls at the fifth percentile.[14] At age 3 they exhibit a WHO_{2007} z-score of -1.93, and at age 18 years they also possess a very similar z of -1.94, at which point many had not yet completed growth. Their growth trajectory is described in the lower panel of Figure 7, along with the resultant z-scores in the upper panel. Instead of z being at a constant -1.9, a greater gap opens up between the deprived girls versus WHO girls, with z falling down to -2.3 at age 13. This is because the well-fed, healthy girls grow faster year-on-year, peak higher, then velocity falls sharply after age 12 (as a prelude to most girls in this group reaching menarche). For the deprived, growth persists. From the start, their rate of growth is below the modern average (WHO_{2007} P50); the pre-pubertal growth spurt is subdued; and – very importantly – growth appears protracted so that from age 13 velocity is above WHO_{2007} and terminal height is reached after age 18. It is this five-years-plus of greater velocity from age 13 that enables recovery.

This continuation of growth into early adulthood suggests the underlying data are composed of (diminishing proportions of) girls who are yet to reach puberty. ‘Catch up’ growth for individuals is possible up to a point (Boersma 1997). In these aggregated, cross-sectional data, the predominant effect is likely to be the delayed maturity of individuals in the underlying population. Even in aggregate, among affluent Indian schoolgirls, puberty appears successively delayed for each decile down the range. Equally important, the tendency to continue growing is inversely related to percentile rank at age 3 (Figure 8): the more deprived pre-puberty, the more the aggregate growth curve is pushed out to older ages, suggesting more individuals reaching puberty at a later age. The upshot is that the timing of the growth spurt matters to the shape of the female z-curve.

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[14] P3 and P5 are the only ranks that start and end on roughly the same distance from WHO_{2007}. All the others suffer from accumulating disadvantage, ending on z-scores below their starting point.

Likewise for the boys. Indian schoolboys at the fifth percentile commenced on a z=-1.93 at age 3, and at 18 had reached -1.90 (slightly better than the girls). At this point these boys were still growing quite rapidly (1.2 inches per year) and when they completed their growth they would be on a higher z-score still (possibly as high as -0.6). This means these boys were doing a little better than the equivalent girls. This makes our comparison of Indian boys and girls close, but slightly favouring the boys. Again, deprivation depresses gains in height, reduces the scale of the pre-pubertal peak, and elongates growth (moreso than for girls who complete growth earlier). The lower the early-childhood percentile, the more subdued the peak, the higher the later velocity of growth (Figure 8). All this bespeaks a greater proportion of the underlying population experiencing delays to puberty. Because boys typically experience a more pronounced adolescent growth spurt (in Tanner's study, over 4 inches per annum, while girls are closer to 3.5 inches) a notably larger gap opens up between deprived boys and the WHO_{2007} standard. See Figure 7 (b). And because peak growth is later for boys than girls, the deprived boys really start slipping further behind the WHO_{2007} standard after age 12 when WHO boys are accelerating rapidly. Indian schoolboys on the fifth percentile dip to a low of -2.4 at age 15.

The differential timing of the adolescent growth spurt – between deprived girls and well-fed girls, deprived boys and well-fed boys, and between deprived girls and deprived boys – throws the z-curves out of synchronicity. We should therefore expect to see a very particular pattern in the z-curves of two equally deprived populations of girls and boys. The form is given in Figure 9 showing the z-curves for Indian girls and boys at the fifth percentile. There should be a double U-shape in the z-curves between the ages of 9 and 18 years, the first U being female, the second being male, with the male U being deeper. (Had we been able to standardise Indian girls and boys more closely, the male U would have been deeper still.) The upswing on each U should coincide with the rapid decline in WHO_{2007} velocity as it is overtaken by the sustained growth of the disadvantaged. The pattern is itself determined by the degree of deprivation, with Us being more pronounced the later the onset of pubertal growth. Because puberty in girls and boys is roughly two years apart, the observed Us should likewise be two years apart. Thus it is not in the absolute values of z-scores alone that we see gender difference; discrimination is to be found in divergence from these predicted forms.

So, if boys and girls are equally disadvantaged across their growing years, we would expect to see two z-curves approximating the shape in Figure 9 of the double-U (male deeper), two years apart, occurring between 9 and 18 years of age. Before and after these ages, the z-scores should be essentially the same. Of course, the curves would look different if the amount of disadvantage changed over the growing years (deteriorating conditions would see z-curves trend downwards; improvements would induce a rise), or if boys and girls experienced differential treatment. Where this is not the case, any comparatively deprived population should exhibit a form of these curves. Interestingly, if we compute z-scores based on WHO_{2007} for the average girl and boy from the 1965 British standard presented by Tanner, Whitehouse and Takaishi (1966a), this predicted shape is evident (Figure 10). It becomes a recurring theme in other historical samples (Figure 10).

Where does this leave our analysis of the Horner data? Clearly, both factory girls and boys in Horner's survey were suffering from undernourishment, with their average figures more than two standard deviations below modern healthy, well-fed girls and boys. These children would become stunted adults, assuming they lived that long. Our *prima facie* evidence suggested that, compared with boys, these girls suffered inferior net nutrition: we conclude that this was, indeed, the case. This is not simply because girls' z-scores fall below boys up to and including age 13, which they do by as much as 0.4 standard deviations: as we have argued, girls' z-scores *should* be lower than boys for a limited time. The real evidence of disparate and unequal growth is that girls' z-scores dip so low that they are on par with the later trough in boys' scores – and this should not happen under conditions of equal treatment. The greater peak velocity of boys should lead to males exhibiting a more profound U than girls: here, they are the same. While we do not know what happened to boys after age 14, the evidence does not point to a lower, later trough: there is evidence of upswing by age 14 and the results appear secure, based on large samples (952 boys at age 14).[15] What is also striking is that the two Us are separated by a mere six months, not two years. Factory girls in Horner's survey were, for whatever reason, falling far behind in the growth stakes.

What do these results imply? First, it remains uncertain whether girls were suffering discrimination, or gender bias, from birth. Their velocity of growth between ages 8 and 9 was close to WHO_{2007}, and the small gap in z-scores at age 8.0 implies that if there was discrimination the effect was not strong. Instead the gap opens up from age 8.5, when Horner's girls' velocity plummets, at a time when it should be accelerating. This would link closely with analyses of mortality that find little evidence of direct gender bias in childhood but do see this emerging in later life, typically in adulthood (Harris 2008, Humphries 1991). Women's own agency in this outcome has led it to be termed 'maternal sacrifice', women going without in order to improve the share of limited resources received by their husbands and offspring. The results here point up something in between. Girls aged 8 ½ are perhaps unlikely themselves to have chosen 'female sacrifice' and the lack of discrimination in their earlier years suggests parents were not engaging in persistent gender bias. In other work 'earner bias' has been suggested (Horrell and Oxley 2013) but, as seen earlier, these factory girls are as valuable to their families at these ages as their brothers. The heights data unequivocally show disadvantage in the allocation of resources against pre-pubertal girls in nineteenth-century factory areas but must remain mute on the source of this discrimination. Below we explore some of the possible causes including occupational sorting, a differential impact of the disease environment, discrimination in food allocation, and greater work effort required in relation to physical capacity.

[15] Tanner (1981, p.149, figure 1) graphs boys' velocity of growth from Horner's, Harrison's and Stanway's data. This clearly shows the upturn around age 14.

Possible areas of differential treatment by gender

Occupational sorting is one possibility. Were healthier boys (but not girls) self-sorting into factory occupations? Peter Kirby has done extensive work on children's sorting and concludes that quite the reverse was occurring: it was the less strong boys who sorted into factory work instead of occupations demanding greater strength, such as mining. He considers there is 'considerable evidence that slender and disabled children were positively selected to work in factories' (2013, p.77) and quotes Hutt, 'children who were insufficiently strong for other employments were sent to the cotton factories because of the lightness of the work there' (Kirby, 2013, pp,122-3).[16] If such sorting was occurring among boys, it was less likely among girls, who faced fewer job alternatives. Occupational sorting offers little to explain the inferior heights of factory girls.

Heights not only capture the effects of nutritional intake but also the demands on that intake, in particular, physical demands from working at young ages and the demands of fighting off disease. What about the disease environment? Were girls more susceptible than boys to poor sanitation and associated disease? Poor sanitation does lead to reduced height (Humphrey 2009).[17] Environmental enteropathy caused by repeated faecal contamination reduces nutrient absorption which may lead to stunting, and at its more severe to malnutrition and cognitive defects, even without necessarily manifesting as diarrhoea. If there is a gender dimension, it appears that boys may be more vulnerable than girls. On the other hand, based on mortality evidence, girls aged 10 to 14 have been deemed more susceptible to respiratory disease, particularly tubercular infections, than boys (Harris 1998, p.446; 2008 pp.170-3). This is attributed to physiological differences in vulnerability rather than occasioned by poor diet, although this is difficult to tease apart as poor diet is known to elevate risk (Ryan Johansson 1977).

If it is differential resistance to disease that is driving the gender difference we observe, we would expect the difference in z-scores between girls and boys to be greatest in large towns suffering the worst urban disamenities. This was not the case. We can divide up the Horner sample by the location in which the data were collected: rural, small town and large town. Although both sexes were more stunted in large towns than elsewhere, the gender gap was actually greatest in rural areas and smallest in the largest towns (Table 11). A possible resolution to this contradiction is that girls more frequently died from respiratory diseases, infections with a very high incidence in nineteenth-century towns, but boys may have been infected at equal rates but survived. This left them more likely to suffer morbidity, and associated stunting, than fatality. Such stunting would reduce the observed gender gap in heights in large towns. We are unable to investigate this further with the data here but the

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[16] Quoted from W. H. Hutt, 'The factory system of the early nineteenth century', in *Capitalism and the Historians* (ed.) F. A. Hayek, Chicago, 1954, pp.160-88, quote p.178.
[17] Also se Dean Spears http://blogs.worldbank.org/impactevaluations. "The Toilet Gap: how much of differences across developing countries in child height can sanitation explain?"

explanation is consistent with our findings and argues against differential resistance to disease driving the gender disparity in heights that we observe.

Another possibility for the more deprived situation of factory girls relative to boys is that despite working and contributing equally to the family's coffers, girls were given fewer resources, in particular less food within their homes. There is general acceptance that a 'female diet', eaten by women and children or, more generally, the 'non-laborious', had emerged by the mid-nineteenth century.[18] Typically women survived on bread and sweetened tea, while the small quantities of meat, cheese and other dairy products affordable to the labouring household were saved for the hard-working man.

Is it the case that differences in the food eaten underlies the differences observed in girls' and boys' heights? In factory areas, reasonable earnings allowed relatively varied food consumption although the quantities are not reported. Mrs B-, the wife of a fine spinner with five children, one of whom was a daughter working for her father as a piecer, reported feeding her family on porridge, bread and milk for breakfast, potatoes, bacon and white bread for dinner, tea, bread and butter in the afternoon, and, usually, oatmeal porridge and milk for supper. Sometimes eggs and bacon were also consumed and Sunday rang the changes with flesh meat and cheese also on the menu (BPP 1833 Factory Inquiry Commission, D1 Manchester, f.649). Similar diets were recorded elsewhere in the report (D2 Manchester p.142). Although female diet was mentioned, it differed little in specifics to the diet of Mrs. B-'s family. Female work people ate oatmeal porridge, milk, tea or coffee with sugar, and bread and butter in the mornings, potatoes and bacon or maybe bread and cheese for dinner at the mill, and a Sunday lunch of meat at home (D1 Manchester f.687; C1 Leeds p.73, f. 407). Mill lads ate much the same (C1 Leeds, p.67, f.401). Elsewhere the report affirms that children ate meat alongside their parents and it draws no distinction between the diet of girls and boys (D2 Manchester p.142).

We can test this possibility further. Utilising the very few accounts of household expenditure available for textile working families amongst the budgets collected by Horrell and Humphries (1992) we investigate calorie and protein intake and see if this systematically differed according to whether there were boys or girls in the household.[19] The fathers worked as spinners, combers, weavers, and handloom weavers but the children all worked in factories. The types of jobs they did were cardsetter, piecer, winder, comber, weaver, and spinner. We convert the food purchased by each household to calorie and protein availability[20] and use an equivalence scale to adjust for the age composition of the

[18] See discussion in Horrell and Oxley (2012) pp.1369-74

[19] We have 11 budgets for households with working children in Manchester and West Yorkshire for the early 1840s: BPP (1842) Children's Employment Commission, BPP (1843) Children's Employment Commission.

[20] The conversion of expenditure to quantities purchased uses retail prices in Manchester in 1841 from Neild (1842, t.3 p.332), supplemented by Smith (1865 p.235) for cheese, eggs and beer. McCance and Widdowson (1991) is used to convert the quantities into kilocalories and grammes of protein.

household.[21] On average across these households there are 1890 kcal per capita per day (2491 kcal per adult equivalent) and 60.5 grams of protein per capita (79.4 g per adult equivalent) available. The variables that can be tested in the regression analysis are limited because of the small sample size (table 10) but the results indicate no relationship between the proportion of females in the household and calorie or protein availability. Thus, we have no indication of any substantial difference in food intake of these factory girls and boys.

If girls and boys were fed equally, could our pattern of gender disadvantage arise from factory girls suffering differentially from the effects of nutritional deprivation? Modern standards for daily energy requirements suggest boys need more calories than equivalent girls, especially after age 12. If fed the same, we would expect boys to fall further behind girls: this is *not* what we observe and acts to further highlight how unusual the relative z-curves are. But there is a further category we need to consider. While developing, humans require a tiny number of calories every day for storing as fat and protein needed for growth. These are additional to those used synthesising new tissue, and they are non-negotiable: without them, the body cannot gain weight and the needs cannot be met by diverting energy expenditures from elsewhere if intake is marginal (Torun 1980, Waterlow 1981). It seems plausible, then, that children are most susceptible to nutritional shortfall when the need to deposit energy is greatest, and the ability to reduce physical activity is limited.

The daily energy requirements needed for energy deposition (weight gain) preliminary to growth in stature (computed as 2 kcal/g new weight (FAO 2001 p.21)) expressed as a percentage of daily energy requirements are given in Figure 11. For Horner's age range deposition needs varied between 16 and 33 kcal/day. If these factory boys and girls were as underfed as appears from their z-scores, these might be 20-30 calories that could not be found. Girls' needs anticipate those of boys from age 7, in both absolute and relative terms though the difference is tiny – just 5 kcal/day at most. If such a small amount matters then, even if equally underfed, the timing of growth means nutritional shortfall would have a more deleterious effect on girls younger than 12, and then on boys over 12.

Work hit Horner's factory children at the moment when the need to develop new tissue and deposit fat and protein was escalating, and for girls before boys. They paid for excessive work and inadequate calories by sacrificing growth, the exchange marked by stunted stature. It is notable that more affluent factory families who could afford more calories did not exhibit the same levels of disadvantage and delayed, deprived female growth: see Stanway in Figure 10(f). Z-scores are not so low, and the gender pattern takes on the predicted form.

Potentially, physical immaturity had a feedback effect through strength. Year for year, there is no evidence of any notable difference in the strength of girls and boys prior to

[21] Man = 1.00; woman 0.90; child aged 11-14 0.90; aged 7-10 0.75; aged 4-6 0.40 and aged 1-3 0.15 (US Congress 1890 p.621).

puberty, although there is a marked disparity afterwards.[22] More important than gender is age. For both boys and girls, strength improves with age. The key here is that, as the factory girls were falling further behind factory boys, they came to resemble biologically younger children. This made girls just a little bit weaker. To match boys on output, but with less strength, they had to expend more energy. A vicious feedback loop then ensued: insufficient calories for growth reduced size and strength, requiring more effort; excessive effort reduced the calories available for growth; and so on. Disadvantage accumulated.

While this mechanism is certainly plausible, what is hard to credit is that a daily difference in energy needs of just 5 calories could be sufficient to drive a pattern of disadvantage that leaves factory girls' growth *so* delayed – by as much as two years – that their adolescent growth spurt nearly coincides with the boys'. So, if it was not unequal nutrition doing the damage, was it unequal work demands? A further possibility is the amount and type of work these children were doing. As we have already seen, girls and boys were doing very similar jobs in the factories, so it is unlikely that type of work itself explains the differences in heights observed. Additionally, there appears to have been no greater incentive to get girls into factory work, and possibly factory work at younger ages, than boys for children aged 11 to 15. Pay relative to non-factory work was high for both boys and girls (table 1) and alternative employment and higher earnings, such as in calico printworks and mines, was available to younger children (Horner 1840, pp.122-4). It is possible, however, that despite similar paid work requirements girls had less genuine leisure than boys if girls were expected to contribute to household labour in addition to paid work. This would increase their work effort and effectively give them a 'double burden'. Of course, following the logic of the unitary model explained earlier, because it was unpaid, girls would not receive material compensation for their loss of leisure. If there is no compensating increase in energy intake the extra effort may result in increased stunting. This would constitute discrimination.

It is difficult to ascertain the relative contributions to domestic labour but there is extensive commentary deriding factory women as poor housewives who sent out for food and paid for their laundry to be done, suggesting that domestic work was minimised in the factory towns (BPP 1833). However, opinion on these women's inadequacies in providing domestic comfort is divided and it was probably no worse than any others of the working class who were living in straightened conditions with poor habitation (Pinchbeck 1977, pp. 309-10). Urban dwellers were more reliant on the services of butcher, brewer and baker for their food than those in rural areas giving rise to the bread, potatoes, bacon and sweetened tea that became the hallmark of the urban diet (Burnett 1989, pp.42-3). Maybe, in towns, girls contributed little time to these tasks and other domestic work, such as collecting water and minding younger siblings was not gendered. But, if we return to the regional differences in height (Table 11), the steadily increasing disparity between girls and boys in small towns and then rural areas may bespeak just such an effect of girls engaging more in domestic labour

[22] For recent works, see Holm et al (2008); Stenevi Lundgren et al (2011).

with the shift from the retail and service amenities of urban areas to the less well-provided countryside.

We should consider whether these regional differences could be driven by factors affecting participation, specifically whether participation rates of girls and boys differed by location and their positioning within the family, where income needs and domestic labour demands had to be balanced. We draw on two Censuses of the Poor for townships in Lancashire[23], which recorded household structure and employment for all poor working households, to examine whether sib-set positioning and, by implication, resources devoted to the individual child, affected participation and hence the likelihood of being found in the factory data. The results are reassuring (table 12). Participation rates were similar for boys and girls in both locations. They started work at similar ages, and working boys and girls had similar numbers of older and younger siblings. Overall, there is no reason to think that the home environments differed substantially between the boys and girls observed working in factories. Housework demands remain the main area of difference. Is it then plausible that this extra physical demand with no compensating energy intake could generate the disproportionate stuntedness of girls that we observe? A realistic calculation suggests that it could.[24] The factory girls would have needed between 300-400 kcal per day more than the boys if they did two hours of housework each day. A slightly larger calorie deficiency (440 kcal) has been associated with a -1.32 z-score reduction in height amongst Australian gymnasts when compared with a control group (Bass et al 2000).

Conclusion

Factory labour by children of 9-12 hours was excessive and stunting. More so, the data on factory children's heights unambiguously shows disadvantage for girls relative to boys in the nineteenth century. This disadvantage apparently was not inherent in earlier childhood years, so cannot be described as gender bias, and it occurred prior to girls having significant agency in decisions, so nor was it female or maternal sacrifice. Despite being of equal economic value as their brothers, these girls had lower net nutritional intake. As far as we can ascertain, occupational sorting does not underlie the difference nor does greater female susceptibility to disease. We do not find direct evidence that this arises from unequal allocation of food, although there is perhaps some room for doubt. The biological argument – of girls anticipating boys in registering stunting – would also apply to other deprived populations and does not explain why Horner's girls are so much more disadvantaged than boys; it also requires too much work from a shortfall of just five calories a day in differential energy needs. That leaves work as the main contender. What remains is the double burden

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[23] Tottington 1817, two miles from Bury in the west Pennines and Bedford, 1835-8, ten miles west of Manchester. Tottington offered handloom weaving, coal mining and calico printing work, Bedford was agricultural but developed a spinning and weaving industry.

[24] Daily physical activity levels are calculated for girls and boys, allowing for an hour of laundry and an hour of floor cleaning to be done by girls (PAL 1.98 and 1.81 respectively). BMR is calculated for each age group using the Harris-Benedict formula on Stanway's height and weight data for factory children.

engendered by engaging in both factory work and domestic labour that may have placed particularly high physical demands on girls, with no compensating nutrition. The impact of arduous physical and mental effort associated with unpaid domestic labour has been pointed up as a factor in women's high mortality (Harris 2008, p.184). We contend that the extension of women's involvement in the domestic sphere to daughters left factory girls undertaking more physical work than their brothers and this was reflected in disproportionate stunting. Indeed, the canonical economic model itself (see p.) takes no account of unpaid work (housework) in its construction instead being, erroneously, satisfied to conflate it with a very different use of time, leisure, and leave it unrewarded. The 'double burden' was, and remains, a form of gender discrimination.

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Table 1. Comparative earnings of factory and non-factory children

	Factory F/M	Non-factory F/M	Females Factory/ Non-factory	Males Factory/ Non-factory	Factory females/ non-factory males
Age					
9	1.14	0.69	1.27	0.77	0.88
10	1.09	0.62	1.57	0.89	0.97
11	0.96	1.22	1.25	1.58	1.52
12	1.04	0.84	1.45	1.16	1.21
13	1.07	1.07	1.34	1.34	1.43
14	1.10	1.06	1.12	1.09	1.19
15	1.03	1.15	1.10	1.23	1.26
16	1.01	0.80	1.07	0.85	0.86
17	0.97	0.77	1.08	0.85	0.83
18	1.03	0.88	1.08	0.93	0.95
Sample size	721/412	114/84	721/114	412/84	721/84

Source: Data collected by Mr. Cowell and calculated and stated by Samuel Stanway from Sunday Schools in Manchester and Stockport. P.P. [450](1833) Factory Inquiry Commission. D1. p.88 f.698

Table 2. Wages and employment in factories

	Age when wages first recorded		Average wage		Wage ratio	Age at which ratio < 1	Average wage		Wage ratio	Numbers employed			
Ages			9-15		9-15		16-20		16-20	9-15		16-20	
Sex	F	M	F	M	F/M		F	M	F/M	F	M	F	M
Lancs cotton	8	8	3.78	3.68	1.03	16	7.27	10.21	0.74	1277	1414	1240	736
W. Riding wool	6	6	4.04	3.83	1.06	16	6.45	9.74	0.68	787	885	559	475
Glos. wool	7	7	2.38	2.79	0.87	10	4.55	6.78	0.69	218	449	166	182
Somerset wool	7	7	2.63	3.07	0.86	8	5.13	7.85	0.64	77	181	91	80
Wilts. wool	7	6	2.62	2.69	0.98	13	4.74	6.38	0.79	165	647	136	235
Derby silk	7	7	3.21	3.28	1.12	15	5.90	11.91	0.53	580	404	450	169
Somerset silk	6	6	2.14	1.76	1.24	17	4.48	6.73	0.75	207	95	170	13
Leeds flax	9	9	3.66	4.31	0.86	11	5.83	9.96	0.64	679	470	596	134
Derby lace	8	9	3.91	3.53	1.12	17	7.72	9.43	0.85	106	72	78	38
Tiverton lace*	10	9	2.56	2.45	1.06	15	4.65	7.68	0.65	68	149	113	67

* from age 10 only. Wages given in shillings per week
Average wage unweighted, i.e.calculated as average wage for age divided by number of ages included.
Average (weekly) net payments to each worker. 'Standard' 69 hour week
Source: Minoletti, P. (2011, app. A) B.P.P. 1834 XIX pp. 279-289.

Table 3. Comparisons of heights 1833 and 1837. Factory children 1833 (Stanway's data) vs those in large towns 1837 (Horner's data)

	Boys (height in inches)			Girls (height in inches)		
	1833	1837	ratio	1833	1837	ratio
Age	Stanway	Horner	Stanway/ Horner	Stanway	Horner	Stanway/ Horner
9	48.14	47.99	1.00	47.97	47.72	1.01
10	49.79	49.36	1.01	49.62	49.12	1.01
11	51.26	50.00	1.03	51.16	50.41	1.01
12	53.38	51.13	1.04	53.70	51.60	1.04
13	54.48	52.99	1.03	55.64	53.32	1.04
14	56.59	55.11	1.03	57.75	55.68	1.04

Sources: B. P.P. (1833) D1 p.88 f.698; Kirby (2010) from BPP (1837)

Table 4. Average height by age (P.P. 1837 (99) Factory Children) (in inches)

Age	Girls James Harrison (Preston) 1833	Boys James Harrison (Preston) 1833	Girls Robert Baker (Leeds) 1833	Boys Robert Baker (Leeds) 1833	Girls Leonard Horner (Large towns) 1836	Boys Leonard Horner (Large towns) 1836
9-10			4' 0.25"	3' 11"	3' 11.75"	3' 11.8"
10-11			4' 1"	4' 2"	4' 1.3"	4' 1.5"
11-12	4' 3.25"	4' 2.75"	4' 2.25"	4' 2"	4' 1.8"	4' 2 1/8"
12-13	4' 5.75"	4' 4.75"	4' 4.25"	4' 4.5"	4' 3.8 "	4' 3.6"
13-14	4' 7.25"	4' 6.5"			4' 5"	4' 5.1"
Ratio (Horner: Harrison/ Baker)						
9-10			0.99	1.02		
10-11			1.01	0.99		
11-12	0.97	0.99	0.99	1.00		
12-13	0.95	0.98	0.98	0.98		
13-14	0.96	0.97				

Bar represents age cut-off in Factory legislation.

Table 5. Relative heights of Factory and Non-Factory operatives (P.P. 1833) Stanway's data.

	Females	Males
	Factory / Non-factory	Factory / Non-factory
Age		
9	0.991	0.990
10	0.983	1.005
11	1.005	0.982
12	1.008	1.001
13	0.991	1.010
14	0.999	0.992
15	1.028	0.989
16	0.975	1.030
17	0.978	0.995
18	0.906	0.969
Sample	652/201	410/227

Source: BPP (1833) D1 p.88 f. 698

Table 6. Measures of skewedness in the heights data

Age (half years)	Female (skewedness)	Male (skewedness)
8.0	-0.24	-0.53
8.5	-0.90	0.10
9.0	-2.7	0.31
9.5	0.26	0.34
10.0	0.37	0.28
10.5	0.04	0.13
11.0	0.61	0.06
11.5	0.13	0.38
12.0	0.62	0.65
12.5	0.49	0.32
13.0	0.68	0.58
13.5	0.32	0.42
14.0	0.02	0.23

Table 7. Girls and boys heights

Age (half years)	Female Height (inches)	Male Height (inches)	Female/ male ratio
8.0	45.08	45.60	0.989
8.5	46.31	46.93	0.987
9.0	47.40	47.65	0.995
9.5	47.96	48.17	0.996
10.0	49.03	49.04	1.000
10.5	49.82	49.68	1.003
11.0	50.24	50.31	0.999
11.5	51.21	51.19	1.000
12.0	51.90	51.77	1.003
12.5	52.64	52.45	1.004
13.0	53.40	53.11	1.005
13.5	54.61	54.18	1.008
14.0	55.98	55.75	1.004
Sample size	8361	8041	

Table 8. Z-score of children's heights

Age	Female z-score	Male z-score	% by which male less disadvantaged than female[1]	Height – percentage less than modern WHO_{2007} standard	
				Female (%)	Male (%)
8.0	-2.29	-2.23	2.7	10.5	9.9
8.5	-2.22	-2.04	8.8	10.2	9.2
9.0	-2.20	-2.11	4.3	10.1	9.6
9.5	-2.41	-2.25	7.1	11.1	10.4
10.0	-2.43	-2.25	8.0	11.2	10.4
10.5	-2.56	-2.34	9.4	11.8	10.9
11.0	-2.83	-2.45	15.5	13.0	11.6
11.5	-2.88	-2.50	15.2	13.1	11.8
12.0	-3.04	-2.68	13.4	13.7	12.7
12.5	-3.10	-2.85	8.8	13.8	13.6
13.0	-3.13	-3.07	2.0	13.8	14.6
13.5	-2.93	-3.13	-6.4	12.8	14.8
14.0	-2.63	-3.00	-12.3	11.4	14.1

[1] Gap calculated as a percentage of male z-score

In making the comparison we use quarter year valuations. That is the original data was collected for the half-year, as stipulated by Horner, so is in the ranges 8.0 – 8.5, 8.5 – 9.0, as so on. We assess these against the mid-point 8.25 (8 years and 3 months), 8.75 (8 years and nine months), and so on.

Table 9. The timing of puberty

Girls Age at menarche (time/place; age)		Boys Puberty (time/ place; age)		
1616-54 Culpepper directory archive	14 ½ - 15			
Early 1700s Jampert, Berlin orphanage	17 +	1723-50 Bach's choir Leipzig	Voice breaking 16 ½ - 17 years	Modern figure UK 13 – 13 ½ years
Mid 1700s Buffon, N. Europe countryside	14	Mid 1700s Buffon, N . Europe countryside	Pubic hair? 16 years	
1781 Edinburgh	13 – 15	1772-94 Carlschule Stuttgart, well off	Peak height velocity 15 ½ - 15 ¾ years	Today, Britain 14 years
1781 Denmen, London	14 – 18			
1830 Whitehead, Manchester factory girls	15.6 years	1800s Marine Society, London; Factories, 1833	Peak height velocity 15 years	Tanner (1981) ½ - 1 ½ years behind today
1828-9 Robertson, Manchester charity lying-in hospital	15.2 years			
1830s London	14.9 years			
1845 Guy, London	15.1 years			
1869 Rigden, UCL, working class	15.0 years			
1910 Edinburgh	15.0 years			
1960s N. England working class	13.6 years			
1960s S. England	13.1 years			

Source: Tanner (1981) pp.20-21; pp.83-84; pp.88-89; p.94; p.112; p.114; pp.155-6; p.158; pp.286 ff.

Table 10. Regression analysis of factory workers' food consumption

	Calories		Protein	
	Per capita	Adult equivalent	Per capita	Adult equivalent
Constant	-2654.46 (-0.88)	2315.35 (3.20)*	-632.10 (-0.73)	67.55 (3.68)*
Total household income	48734.53 (1.94)[x]	276.03 (0.47)	1596.17 (2.40)*	13.10 (0.88)
No. in household	5828.68 (0.98)		260.05 (1.65)	
% household members work	219.74 (0.54)	-1.44 (-0.13)	8.23 (0.76)	0.04 (0.13)
% household members female (as a proportion of adult equivalents)	-180.78 (-0.41)	-1.01 (-0.08)	-7.97 (-0.68)	-0.11 (-0.32)
Adjusted R^2	0.59	-0.38	0.75	-0.25
Sample size	11	11	11	11
F	4.56[x]	0.08	8.67*	0.34*

*Indicates significance at 5% level or higher, x at 10% level, t-ratios in parentheses.

Table 11. Differences in mean z-score for height by location

	Large town	Small town	Rural
Girls' mean z score	-2.91	-2.79	-2.68
Boys' mean z score	-2.84	-2.69	-2.54
Difference	-0.07	-0.10	-0.14
t-test for equality of means (significance, two-tailed)	0.02	0.00	0.00

Table 12. Household structure and children's participation from Censuses of the Poor

	1817 Tottington, Lancashire 191 households		**1835-8 Bedford, Lancashire** 60 households	
	Boys	**Girls**	**Boys**	**Girls**
% sample (no. children)	51.4 (599)		52.8 (177)	
% working	27.4[a]	22.4[a]	32.6	31.4
Average earnings of father (£):				
Child working	23.57	23.52	25.55	25.18
Child not working	25.56	24.46	24.55	25.89
Children working only:				
Mean age	8.39	8.36	8.62	8.41
No. in household – range	4 - 11	3 - 11	7 - 11	7 - 11
No. in household – mean	8.39	8.36	8.62	8.41
No. younger siblings	4.46	4.42	4.76	4.74
No. older siblings	0.90	0.88	0.86	0.67

[a] A Pearson chi-squared test shows this difference in participation rates to be insignificant (1.976, sig 0.160)

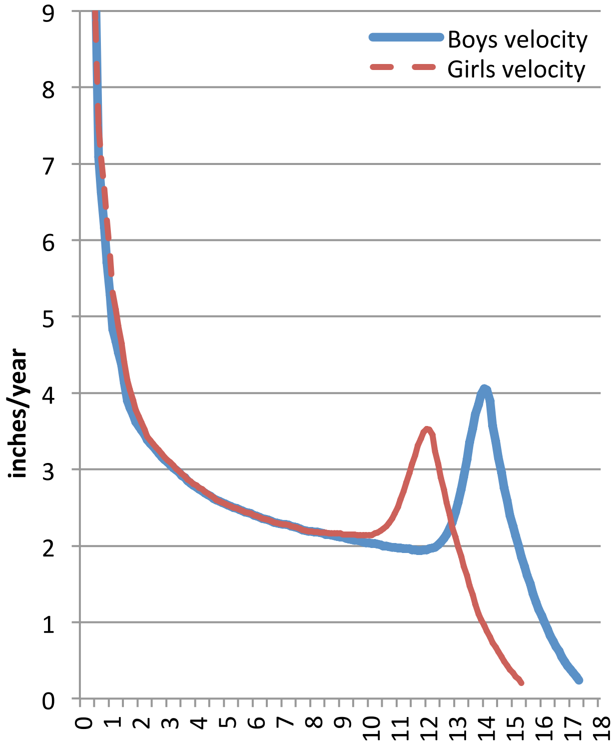

Figure 1. Individual velocity curves (peak velocity centred) redrawn from Tanner, Whitehouse and Takaishi (1966a) p.466

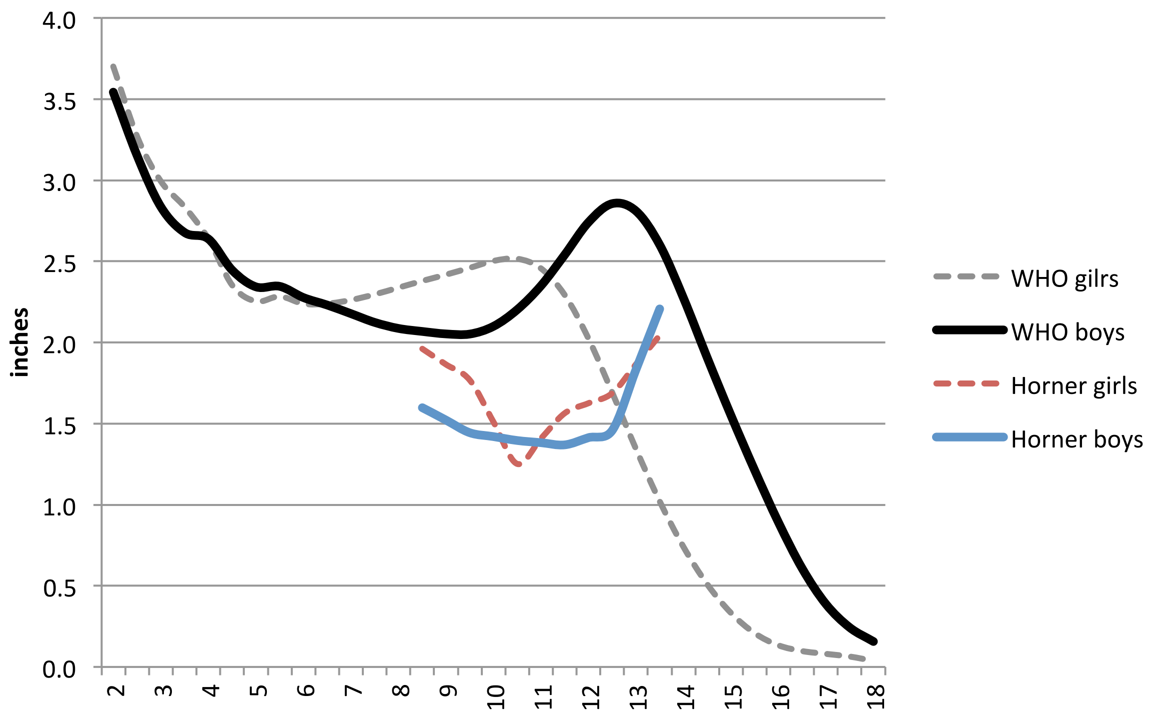

Figure 2. Annual growth intervals WHO_{2007} and Horner's factory children 1837

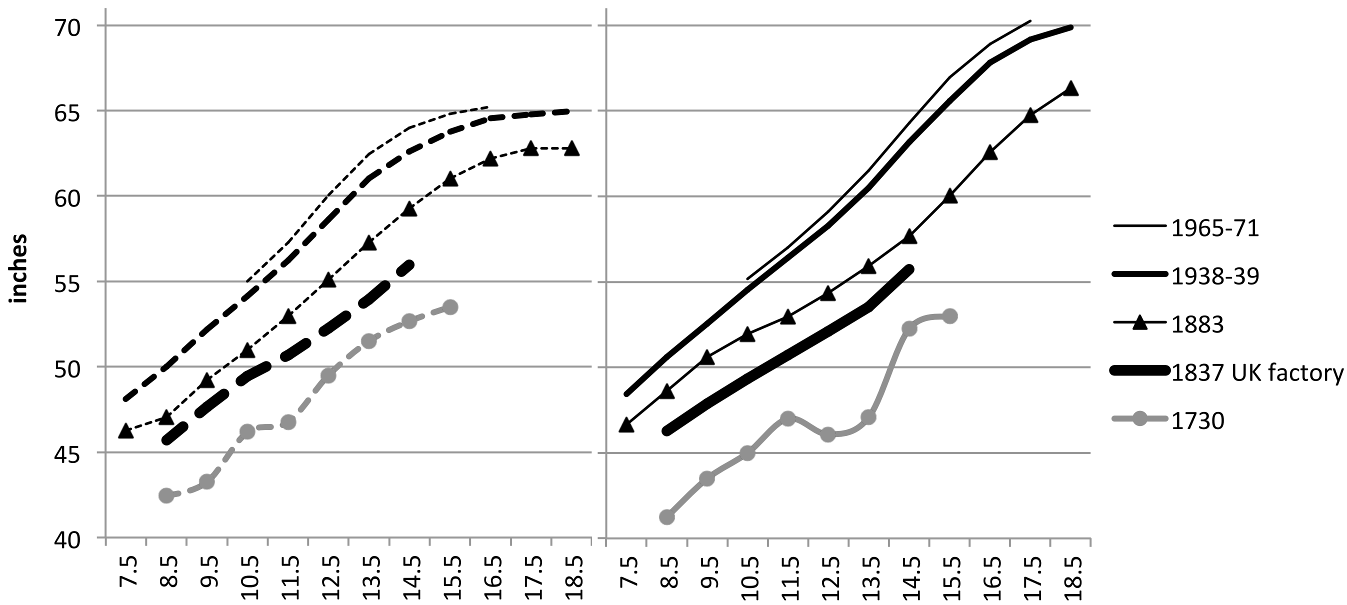

Figure 3. Secular trend in growth of height. Reproduced from Ljung (1974, p.247) and annotated.

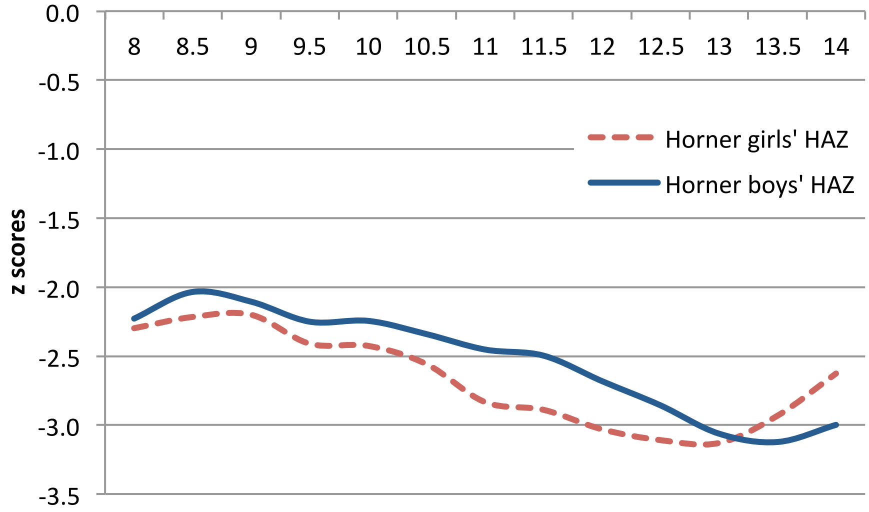

Figure 4. Height for age z-scores for Horner's factory children, 1837 (WHO_{2007} base)

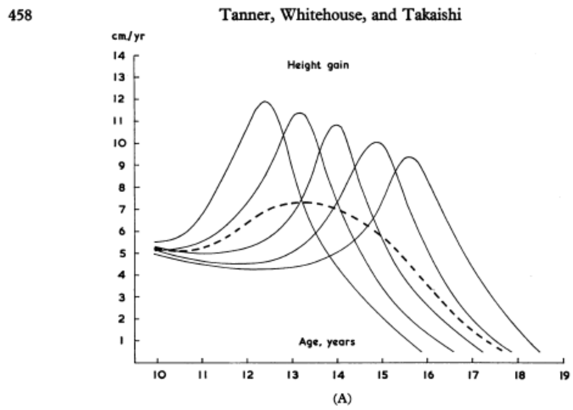

Figure 5. Reproduced from Tanner, Whitehouse and Takaishi

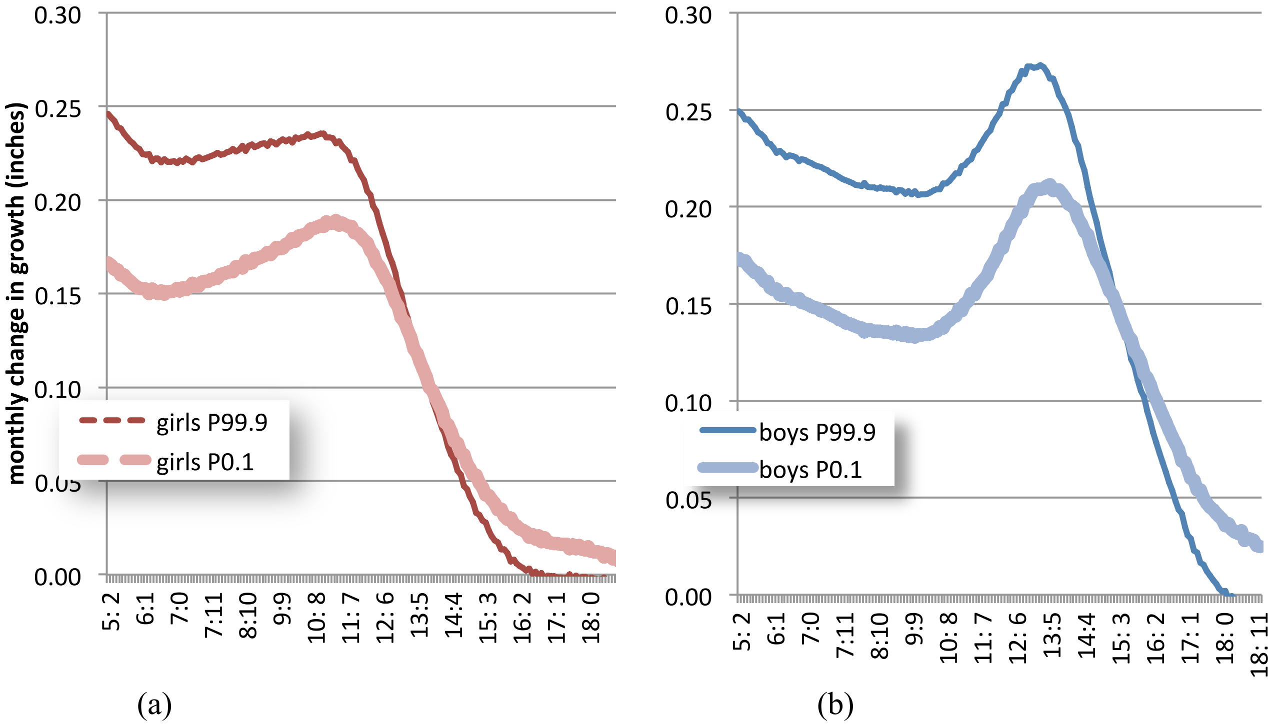

Figure 6. Monthly growth intervals for WHO_{2007} percentiles 0.1 and 99.9 for (a) girls and (b) boys

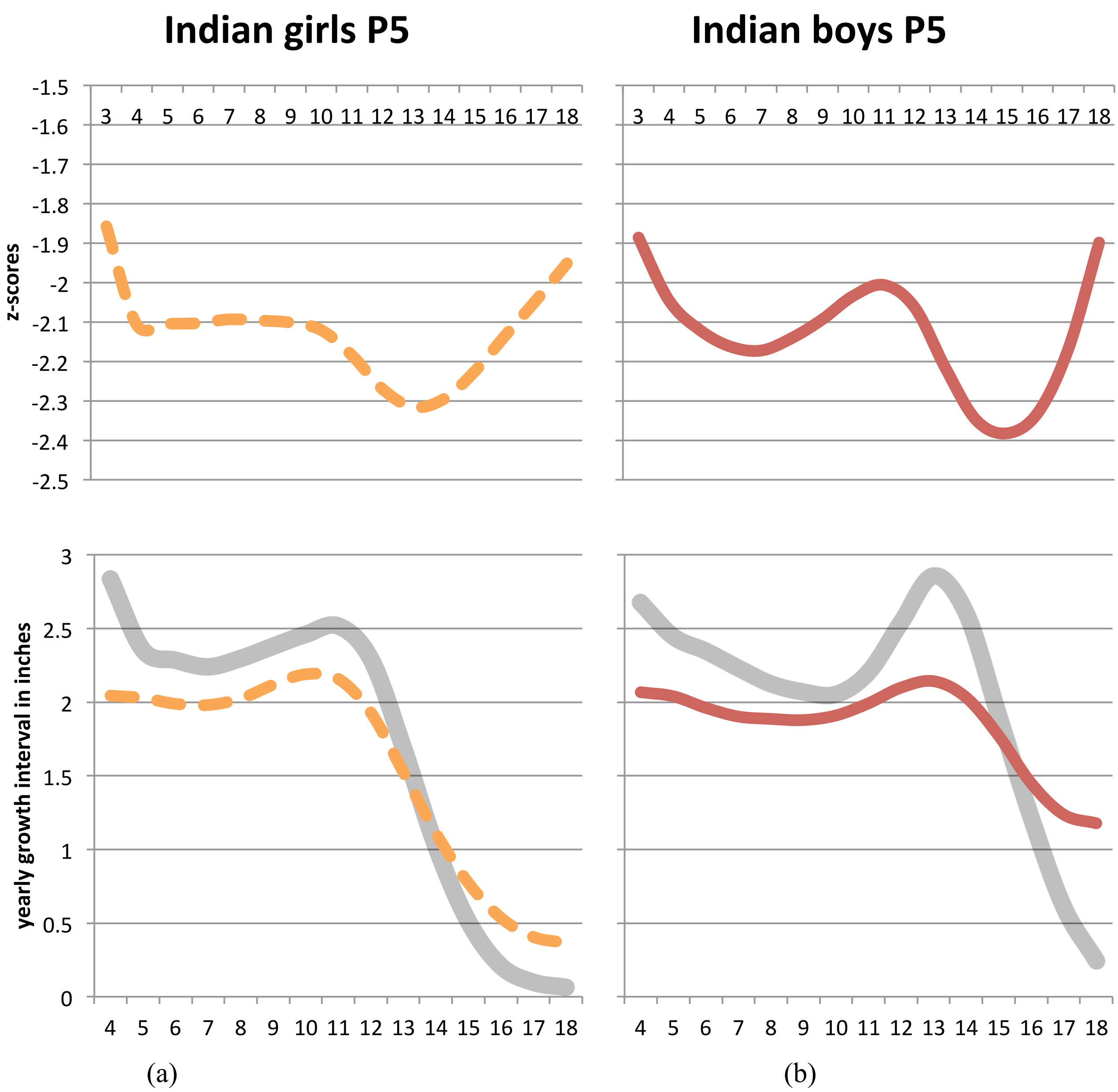

Figure 7. Indian schoolchildren (upper socioeconomic strata) at fifth percentile: z-scores, growth intervals, and WHO_{2007} for (a) Girls and (b) Boys

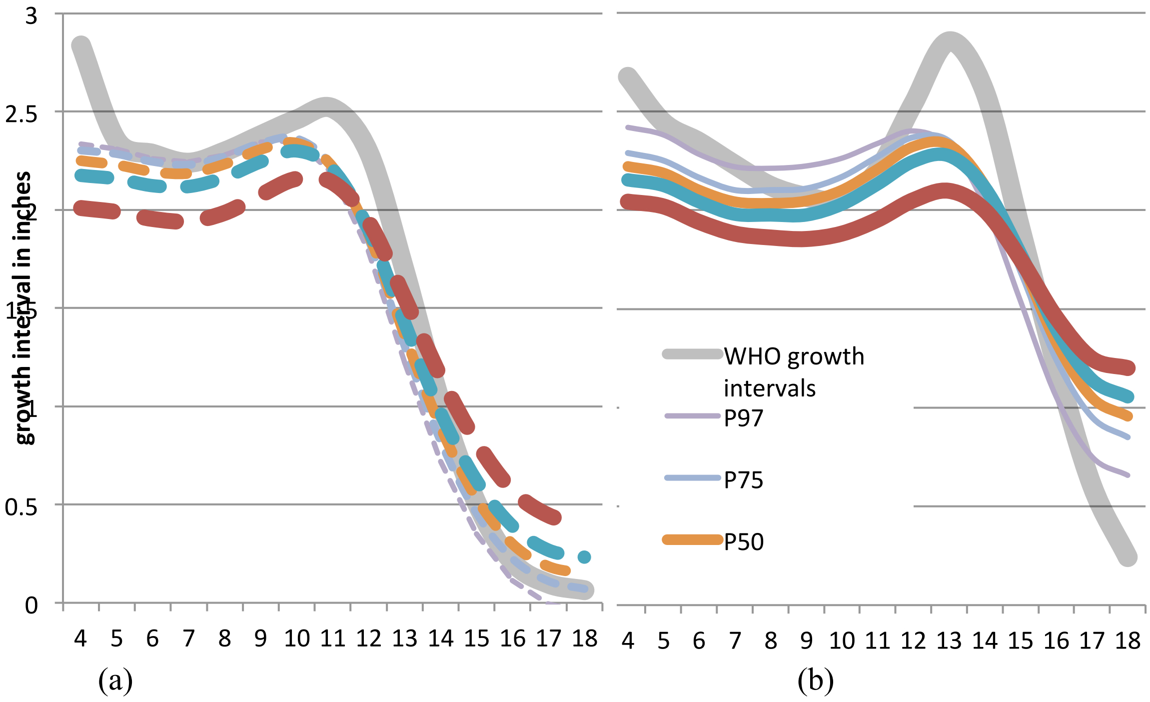

Figure 8. Growth intervals of Indian schoolchildren (upper socioeconomic strata) and WHO_{2007}

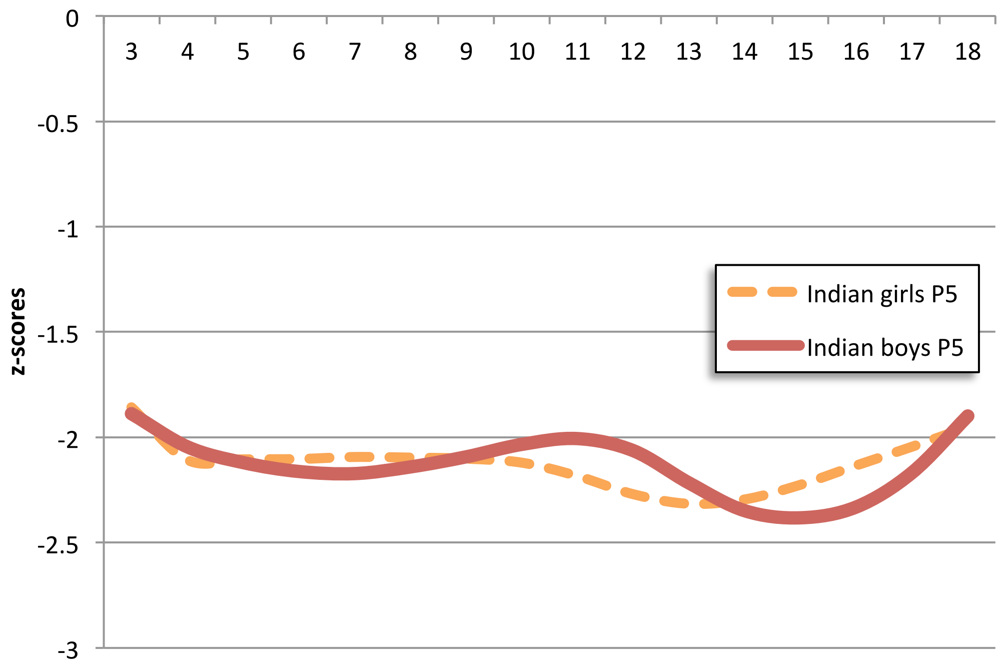

Figure 9. Indian girls and boys at the fifth percentile compared with WHO_{2007}

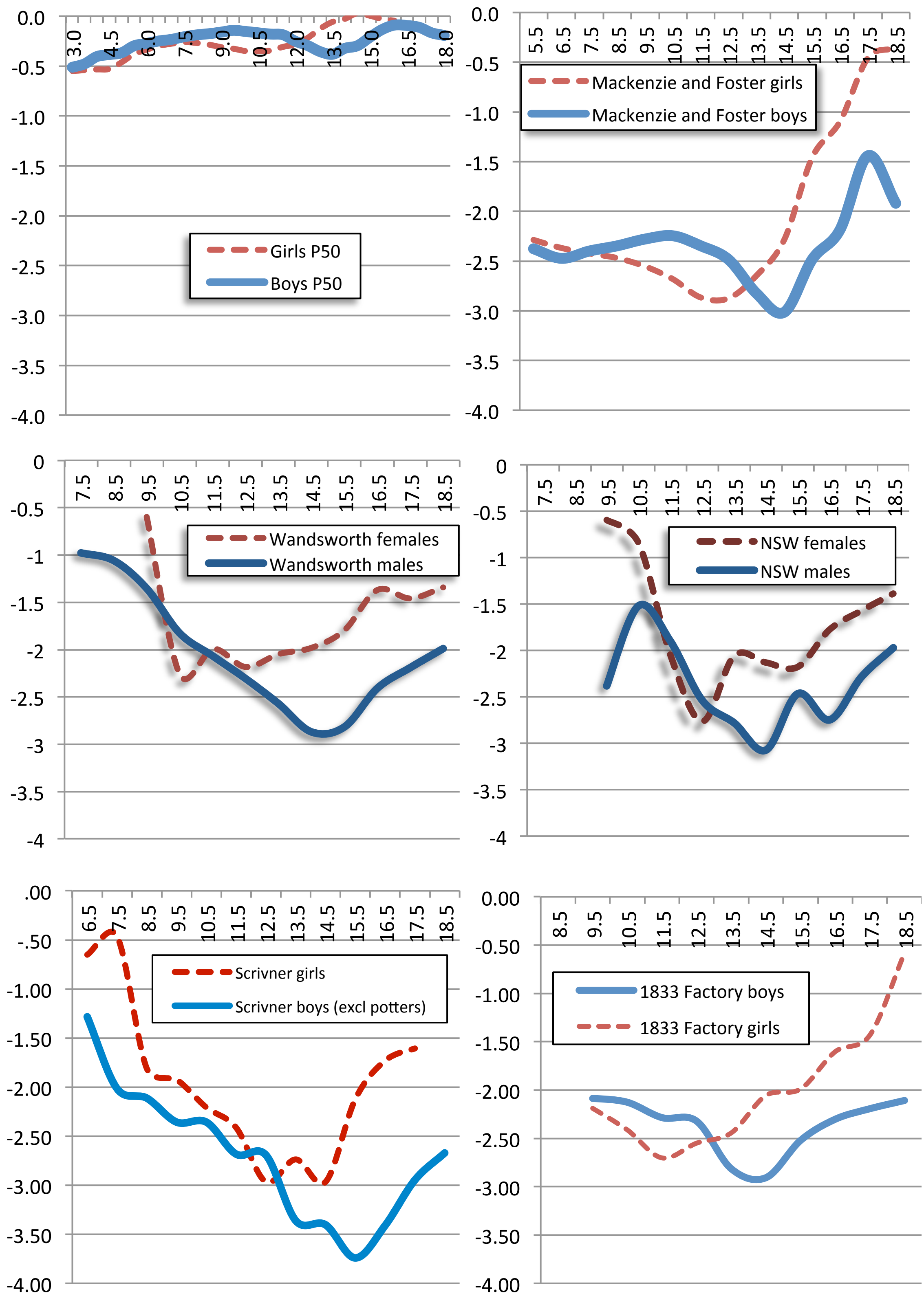

Figure 10. Historical examples (a) 1965 British standard, (b) Glasgow schoolchildren 1907, (c) Prisoners from the Wandsworth House of Correction 1848-75, (d) Convicts transported to NSW c.1818-40, (e) Scriven's and Symon's colliery, farm and worsted mill workers, 1841 and (f) Stanway Sunday School children 1833, all compared with WHO_{2007}

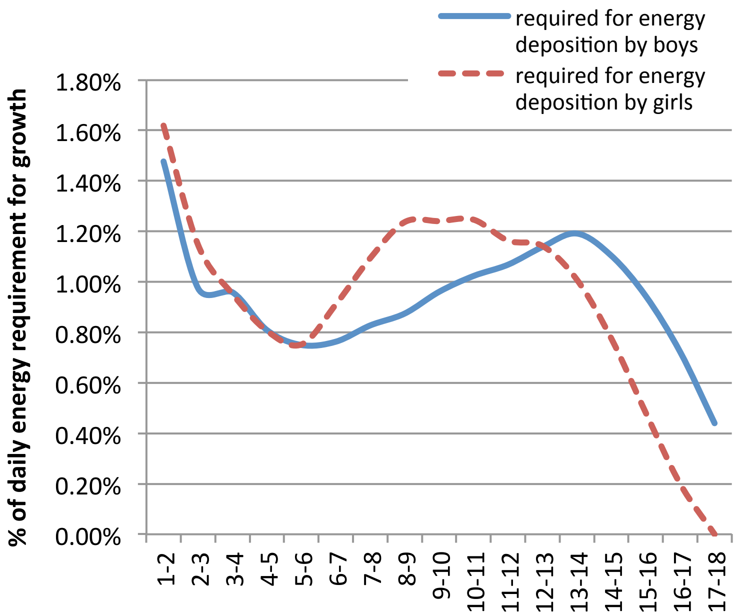

Figure 11. FAO Human energy requirements (2001), pp.26-27